Passive multiples and friends

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Contents

Introduction

This is a set of notes on building passive multiples, and a few related projects, for Eurorack modular synthesizers.

Many synth patches involve using one module output to drive more than one module input, and achieving that requires some kind of adapter or splitter. There are a number of different ways to split a signal, including outboard adapters, cables with stackable connectors, and modules installed in the synthesizer rack specifically for splitting signals. In the modular-synth hobby, these modules are called *multiples* or *mults* (not “multipliers”; that term usually describes a different function). Multiples can be *passive*, meaning that they contain no active components and just connect inputs and outputs, or *buffered*, if they contain distribution amplifiers that boost the available power of the signal and prevent inputs from influencing each other.

A basic passive multiple is just some jack sockets stuck in a panel, with all the tip and all the sleeve contacts wired together. They are so simple that one might not bother with formal plans or a circuit diagram, but just wire up a multiple ad hoc whenever needed. But passive multiples are also often recommended to beginners as projects for soldering practice, and the exact details of the wiring do rank as frequently-asked questions.

These notes are for anyone unsure about exactly what needs to connect where when building a passive multiple; and these notes come with a set of Gerber files for a 2HP PCB panel, which may save some time for anyone who wants to get such panels made up. The physical design aspects of a project (dimensions, locations, making sure each thing fits into its space) are often underestimated and these notes are meant to reduce the work needed on those points.

Although this is a budget design, without things like a proper aluminum panel that I’d consider necessary for a commercial version, it’s meant to be a best-practices version of what it is. I’ve included some non-obvious points like normalization, which many commercial passive multiples omit. I also describe some other unpowered modules which can be made with the same panels and a few added parts.

Panels

Wherever you got these notes, you should also be able to find a ZIP archive of Gerber files for a PCB design that can serve as a 2HP front panel. The panel design is shown in Figure 1. On one side it groups the jack sockets into groups of four, and on the other side into groups of two. It’s symmetric so that if you get the boards made up with both sides of silkscreening, then you can flip the board to either side to choose either art. Note that with the groups of two, it may make sense to combine more than one project (such as high and low pass filters) into the same module instead of doing a quad version of a single function. At the end of these notes there’s a mechanical drawing showing my suggestions for hole sizes and locations; that may be useful if you want to redraw or modify the panels.

Ideally, the panel ought to be 2.0mm thick. That is more than the popular default PCB thickness of 1.6mm, and most fabs will charge extra for the thicker board, so you might save money by using the default thickness instead. However, in that case, the panel front surface will not sit flush with other panels that really are the standard 2.0mm. Also, given that fibreglass PCB material is already less stiff than a standard aluminum panel, it’s nice to have the extra thickness to make it as rugged as reasonably possible. If you’re buying a reasonable-sized batch of boards and using decent-quality jack sockets then you will probably end up spending more money on the jack sockets than the boards anyway, so there may not be much point pinching pennies here.

Similarly, I suggest using lead-free HASL boards for PCB panels rather than the very cheapest lead-alloy HASL, because the boards are exposed to the user’s fingers in this design, and if they’re coated in lead then anyone who touches the synthesizer probably ought to wash their hands afterward. However, any exposed metal on the panel will likely end up covered by jack nuts and mounting screws, so lead is less an issue in this design than it might be with other PCB panels. There’s similarly no real point to

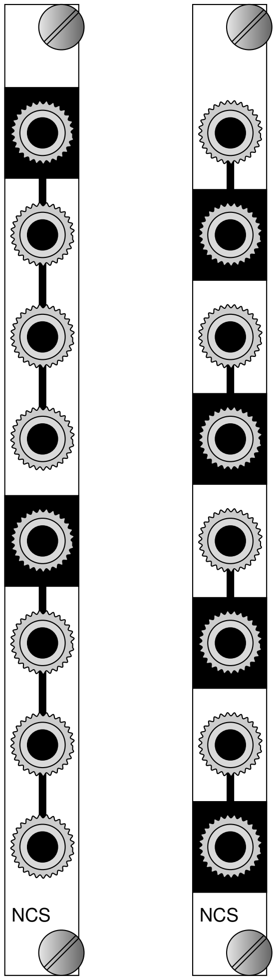


Figure 1: Panel designs.

opting for gold plating on this project if that costs more, because the gold won't be visible in the final installation anyway. This design does not depend on the panel for electrical conductivity, so the electrical properties of the plating are not especially important.

I had my panels made with 1oz copper on both sides, which was my fab's default. Having that copper helps improve shielding and stiffnees, but is not really absolutely necessary. If I could get thicker copper at the same price I would have chosen it; if thinner copper, or not having it on both sides, would have meant a lower price, then I would have chosen that.

It may be advisable to tell the fab that you will be using these PCBs as panels and that the complete coverage of copper on both sides is deliberate. Some fabs, when reviewing the design to make sure they can read the files, will think solid copper areas with no traces at all look like a possible error if you don't notify them that it was done on purpose.

I chose a white solder mask with black silkscreen for my own batch of panels and the result looks pretty good next to the uncoloured anodized aluminum of most of my modules. Obviously, you can choose to have them made up in whatever colours your fab offers. The silkscreen design is deliberately generic, just showing the eight jacks grouped in two sets of four with the top one in each set marked as different, so that it can work for any of the variations in these notes. If you're going to build more than one variation (such as passive multiples and also OR combiners) then it would make sense to add markings to the panels, even if just with felt pens, to keep track of which modules are which.

Jack sockets

Each module built according to these notes, in any of the variations, will require eight jack sockets. I used Lumberg 1502 03 jack sockets, because those are the ones I keep in stock for my commercial projects. They are high-quality mono 3.5mm phone jack connectors and they fit, just barely, in the 2HP of available space.

It should be possible to substitute other kinds of jack sockets with the same panel design; most connectors in this class will fit in the 6.3mm holes I specify in the Gerbers. However, be aware of the width of the connectors behind the panel. Some 3.5mm jack sockets (e.g. MJ-3536 type) are a little wider and the module built with them may not really fit in a 2HP rack space. Also, you will have to know the pinout of whatever connectors you use and modify the wiring diagrams accordingly.

Wire and soldering

Passive multiples are often recommended to beginners as simple projects for soldering practice, and I have mixed feelings about that because soldering so-called "flying" wires to panel components, as in this project, is very fiddly and frustrating, and does not use exactly the same techniques as soldering components to a PCB. It may not be the gentlest introduction to soldering for a first-time builder and it may not be the most useful practice for someone who will then switch to building circuit boards.

Without turning these notes into a "how to solder" guide, I'll say it's worth remembering every solder joint is really two: the *mechanical* joint that holds the things together and the *electrical* joint that conducts current. To the extent possible, it's best to make the mechanical joint first by bending and twisting wires so that they will stay in place even without solder; then go in and apply the solder just to form the electrical joint.

I suggest solid wire for this project because it's easier to handle, more stable, and the wires should not be flexing during normal use. In my own builds I used bare wire for the ground connections, which made it easier to thread a single piece through the grounding lugs on multiple jack sockets; but for the other connections I used insulated wire cut into separate pieces point-to-point and that might actually have been a good idea for the grounds as well because threading the solid wire through was still quite annoying.

Choose a wire diameter such that you can easily handle it and can easily connect at least two wires to each lug on the jack sockets. I used 22 gauge solid unplated copper wire because I had some on hand that I wanted to use up; but I would have chosen 24 gauge to make it easier to thread through holes, and pre-tinned for easier soldering, if I were choosing freely.

Safety and other warnings

Ask an adult to help you.

Soldering irons are very hot.

Solder splashes and cut-off bits of component leads can fly a greater distance and are harder to clean up than you might expect. Spread out some newspapers or similar to catch them, and wear eye protection.

Lead solder is toxic, as are some fluxes used with lead-free solder. Do not eat, drink, smoke, pick your nose, or engage in sexual activity while using solder, and wash your hands when you are done using it.

Solder flux fumes are toxic, *especially* from lead-free solder because of its higher working temperature. Use appropriate ventilation.

Some lead-free solder alloys produce joints that look "cold" (i.e. defective) even when they are correctly made. This effect can be especially distressing to those of us who learned soldering with lead solder and then switched to lead-free. Learn the behaviour of whatever alloy you are using, and then trust your skills.

Water-soluble solder flux must be washed off promptly (within less than an hour of application) because if left in place it will corrode the metal. Solder with water-soluble flux should not be used with stranded wire because it is nearly impossible to remove from between the strands.

Use and contact information

I don't think there is a good business case for me to sell passive multiples, neither assembled nor as DIY kits. However, I needed to do some design work on these just to get the panels made so I could build a few for my own use, and it seems worth sharing that. There's also some benefit to writing up the notes on how to use the panel design, as a bit of content for my Web site. Accordingly, I am releasing this design and set of notes as public domain. People who want to use it can get the panels fabbed themselves.

I don't plan to offer a commercial version. If someone else wants to, that's their business. I'm also probably not going to go to the effort of making a relatively polished "source" package for the design because the design is so simple and the files from which I generate the Gerbers and document are tied into a lot of baggage from my in-house software tools. If you want a modified silkscreen or something, I encourage you to simply redraw it with your choice of software. The dimensions in the mechanical drawing may be of some help for that.

However, I sell other modules, both as fully assembled products and do-it-yourself kits, with more elaborate source code available, from my Web storefront at `http://northcoastsynthesis.com/`. Your support of my business is what makes it possible for me to continue releasing module designs for free. The latest version of this document can be found at that Web site.

Email should be sent to
`mskala@northcoastsynthesis.com`.

Passive multiple

The basic function of a multiple is to distribute a signal from a source to multiple destinations. For instance, a gate signal from a controller or sequencer might be used to drive multiple ADSR envelopes. The connections are as shown in Figure 2. The signal source is patched to the module input, and the module outputs are patched to the signal destinations.

With my suggested wiring, the two module inputs are normalized to each other using the switches built into the jack sockets. Patch a signal source into *one* of the module inputs, either one, and the signal will appear at all six module outputs. Patch signals into *both* module inputs, and each signal will be distributed to three of the module outputs, in the groups indicated by the markings on the panel.

Limitations of passive multiples

Passive multiples should only be used to split signals from single sources to multiple destinations. Patching more than one source into the same multiple group will cause a conflict between the sources as they each attempt to drive the combined connection to their own preferred voltage. It is traditional to warn synth users that patching outputs into each other, directly or through a multiple, may damage the modules. In practice, permanent damage would be quite unusual, but this kind of patching is at least unlikely to have a useful effect, because the outputs will not operate normally when overloaded. If you want to mix outputs, you need a mixer of some kind. There is a simple passive mixer design described in the next chapter of these notes.

When one source drives two or more destinations through a passive multiple, the impedance seen by the source is the parallel combination of all the destinations it is driving. Eurorack inputs have a typical impedance of 100kΩ; with up to six of them driven through this multiple module, the resulting impedance seen by the signal source could be as low as about 17kΩ (that is, 100kΩ÷6), even less if the inputs do not really have the standard impedance. As a result of the lowered input impedance, some signal sources that themselves have higher-than-normal

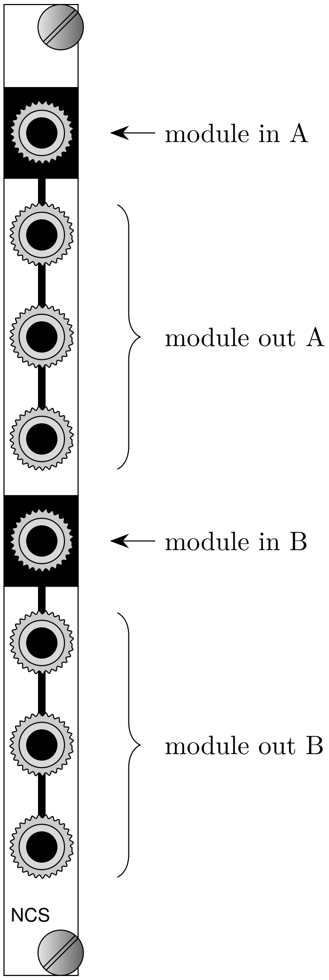


Figure 2: Passive multiple connections.

output impedance may not be able to drive the voltage of the combined connection as well as they might drive a single destination.

In practice, the effect of overloading a signal source shows up as reduced volume on audio, pitch going flat on pitch control voltages, and so on. The way to avoid the problem is to use a buffered multiple instead; but buffered multiples are more complicated and expensive, and require a connection to power. Many people want to use passive multiples like this one, but it's a trade-off; passive multiples are only appropriate for situations where the exact voltage is not critical, or where the source of the signal has a low enough impedance to drive all the inputs in parallel.

Another minor issue with unbuffered multiples is that jack sockets usually create a brief short circuit between tip and sleeve whenever a plug is inserted or removed. Because all the output jacks in a group on this module are directly connected to each other, shorting one jack affects all the others. So if you have some output jacks patched and you patch into or out of another jack, the already-patched ones will hear a click or interruption in the signal. Such a click will not usually be a significant problem, but it's worth knowing about, and it is another of the compromises that result from having a completely passive circuit.

Building the module

You will need the panel PCB, eight jack sockets, and some wire. See the comments in the introduction regarding details of these things.

Install the jack sockets in the panel PCB as shown in Figure 3, which is a view from the back of the module. Make sure the side you want to be at the front of the installed module (probably the "groups of four" side) really is facing outward, that is, away from you as you look at the back of the module. When viewed from the back, the mounting screw holes should be nearer the viewer's left, as shown in the diagram, to ensure that the panel will be right side up when completed. Try to get the jack socket bodies as straight as possible, because if they are twisted at all then the module will not fit well in a 2HP space next to other modules.

Connect all the sleeve contacts (grounds; shown as pale orange-pink wire in the diagram) to each other. I suggest doing those first because these wires can fit comfortably under the other ones. I usually use bare copper wire for these connections because it's possible to thread a single long wire through all eight lugs, but doing that is somewhat fiddly and makes it necessary to carefully avoid contact with other things. It may not really be any easier than using several short pieces of insulated wire.

Connect the tip contacts together in groups of four, as shown by the green wires in the diagram. Connect the combined tip connection of each group to the normalling contact of the top jack socket in the *other* group, as shown by the red wires. It is not necessary to actually use those colours of wire; they were chosen to make the diagram easier to read.

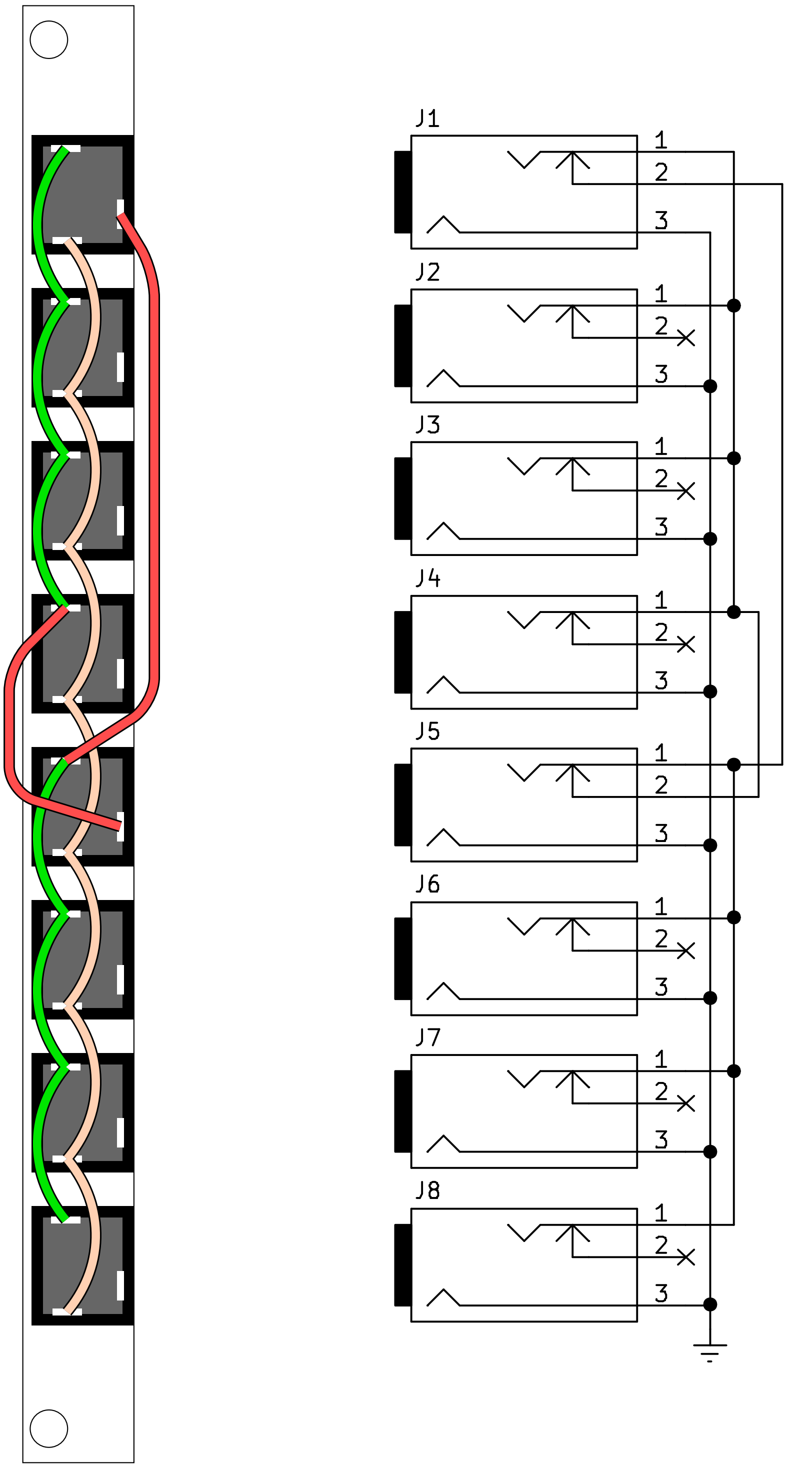


Figure 3: Passive multiple schematic and wiring.

Fixed passive mixer

This is a simple way to combine several signals in equal proportions. The output voltage (neglecting losses resulting from impedance issues) is the average of the input voltages.

With my suggested wiring, the two module outputs are normalized together using the switches built into the jack sockets. If you patch from just *one* of these outputs, it will be a mixture of all six inputs. If you patch from *both* module outputs, each one will be a mixture of the three inputs in its group.

I suggest using 10kΩ resistors in this mixer design. The worst-case input and output impedances for this module both end up close to the resistor value, and 10kΩ is a reasonable compromise between the Eurorack targets of 100kΩ input and “low, at most 1kΩ” output. If you have a specific need for higher or lower impedance you could substitute some other resistor value, but doing so may simply be trading one problem for another.

As with almost any unpowered module, there will necessarily be some loss of signal strength passing through this mixer. The modules you patch into it on both input and output should not also be unpowered; having it work correctly depends on those other modules following the standards for impedance which this module doesn’t. Not also that this is an *averaging* (not *summing*) mixer, and there will also necessarily be some loss of volume as a consequence of that. For example, with two inputs of 5V and 0V the output will be at best 2.5V because that is the average of 5V and 0V – then reduced to about 2.4V if it’s driving a 100kΩ input impedance further downstream.

Building the module

You will need the panel PCB, eight jack sockets, six resistors of the same value (I suggest 10kΩ), and some wire. See the comments in the introduction regarding details of the panel, sockets, and wire.

Install the jack sockets in the panel PCB as shown in Figure 5, which is a view from the back of the module. Make sure the side you want to be at the front of the installed module (probably the “groups of four” side) really is facing outward, that is, away from you

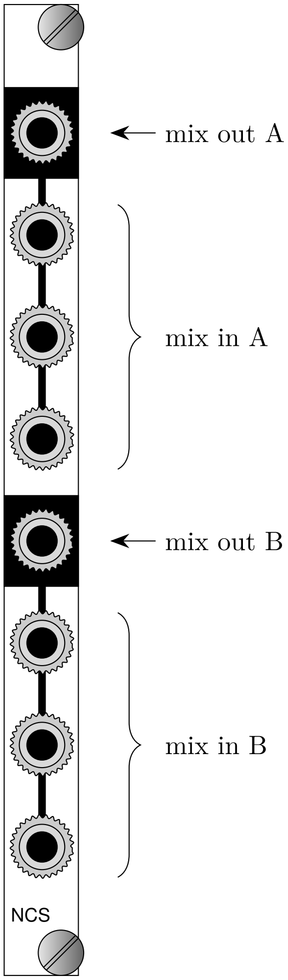


Figure 4: Passive mixer connections.

as you look at the back of the module. When viewed from the back, the mounting screw holes should be nearer the viewer's left, as shown in the diagram, to ensure that the panel will be right side up when completed. Try to get the jack socket bodies as straight as possible, because if they are twisted at all then the module will not fit well in a 2HP space next to other modules.

Connect all the sleeve contacts (grounds; shown as pale orange-pink wire in the diagram) to each other. I suggest doing those first because these wires can fit comfortably under the other ones. I usually use bare copper wire for these connections because it's possible to thread a single long wire through all eight lugs, but doing that is somewhat fiddly and makes it necessary to carefully avoid contact with other things. It may not really be any easier than using several short pieces of insulated wire.

Connect a resistor to the tip contact of each of the six jack sockets indicated. Connect the other ends of the resistors together in groups of three, and those joined connections to the remaining two jack socket tip contacts. It is probably easiest to bend the wire resistor leads and use those to make the connections in a daisy-chain fashion, as shown by the grey wires in the diagram.

Connect the combined connection from each group to the normalling contact of the output jack socket for the *other* group, as shown by the red wires. These wires can connect to the chained resistor leads at any convenient points along the chains; it is not necessary to follow exactly the layout shown, although it may be a convenient one.

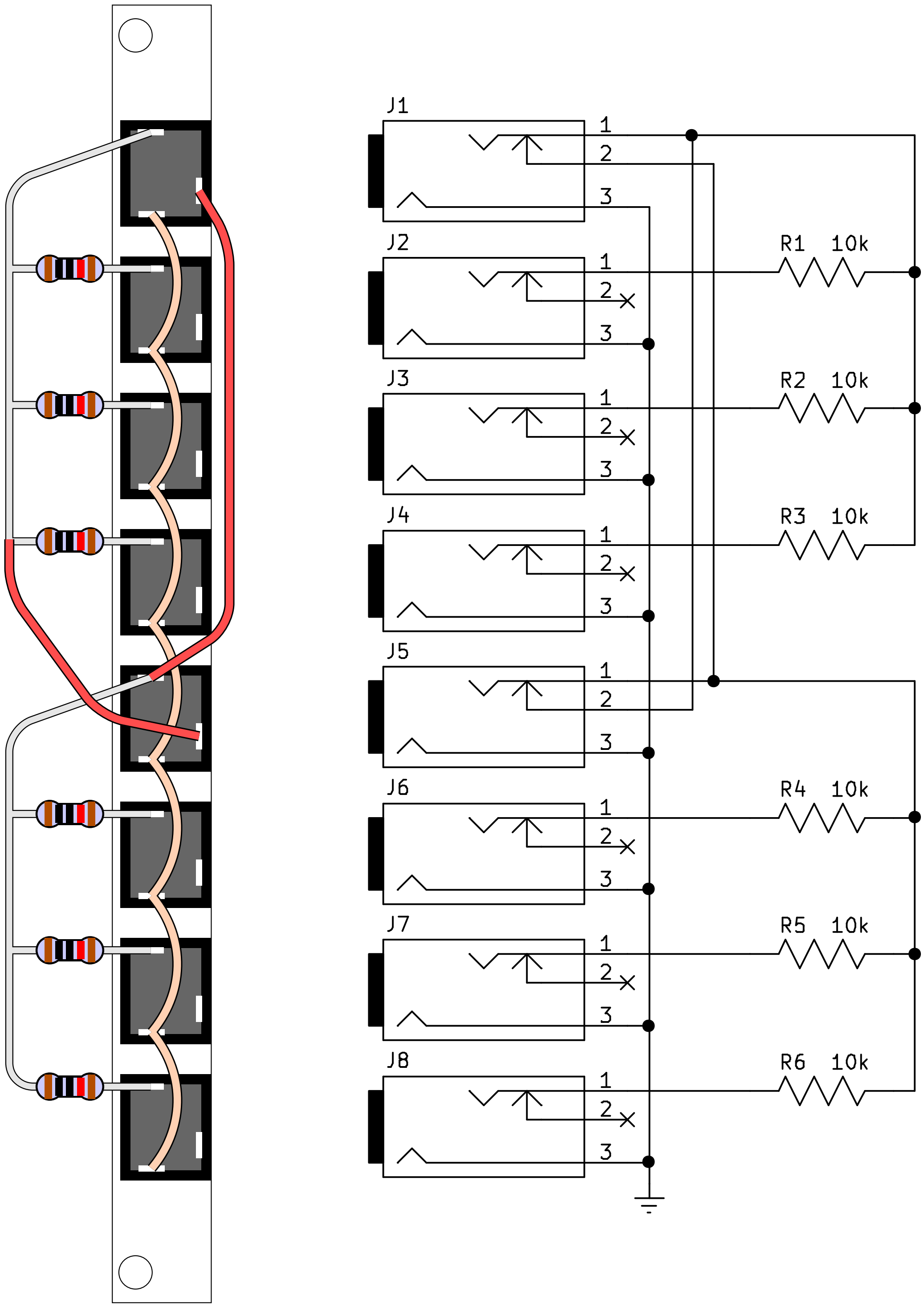


Figure 5: Passive mixer schematic and wiring.

OR combiner

This OR combiner is intended for use with typical modular gate or trigger signals. The output goes high when at least one of the inputs is high, and is otherwise low (0V). The front panel connections are as shown in Figure 6.

As with the passive mixer, my suggested wiring normalizes the two groups of four jack sockets together, so that if you plug into just one of the output jacks it will be the OR combination of all six inputs, and if you plug into both outputs, each group output will be the OR combination of its own three inputs.

The "OR combination" function performed here is technically finding the *maximum* of any input voltage minus one diode drop, or zero; so putting in several 5.0V gates will give an output of about 4.3V, and putting in a 10.0V and a 5.0V gate will give output of about 9.3V. Most modules that accept gates are quite forgiving of wildly variable voltages; but it's worth knowing that there is this voltage loss (pretty much inevitable with an unpowered module) and using very low input voltages, or chaining OR combiners of this kind together, may give unsatisfactory results.

I recommend using 68kΩ resistors as a good compromise between low enough impedance in the low state for downstream modules to recognize that state as "low," and high enough impedance in the high state not to produce much voltage loss beyond the loss from the diodes. However, the output impedance in the low state can be as high as the resistor value and it's possible downstream modules may not like that. You can reduce it by reducing the resistor value.

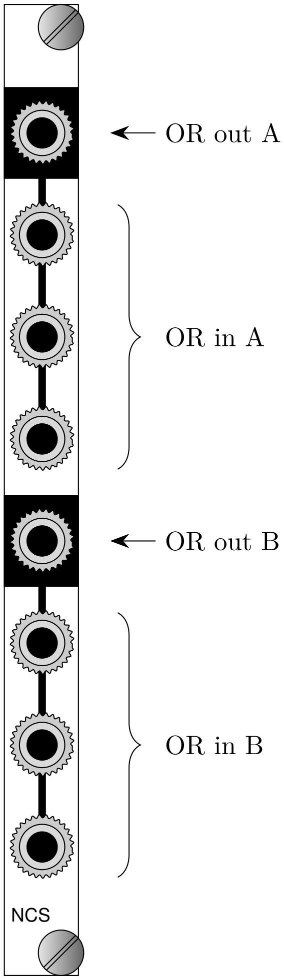


Figure 6: OR combiner connections.

Building the module

You will need the panel PCB, eight jack sockets, six general purpose diodes (I recommend 1N4148 but any similar diode should be fine), two 68kΩ resistors, and some wire. See the comments in the introduction regarding details of the panel, sockets, and wire.

Install the jack sockets in the panel PCB as shown in Figure 7, which is a view from the back of the module. Make sure the side you want to be at the front of the installed module (probably the "groups of four" side) really is facing outward, that is, away from you as you look at the back of the module. When viewed from the back, the mounting screw holes should be nearer the viewer's left, as shown in the diagram, to ensure that the panel will be right side up when completed. Try to get the jack socket bodies as straight as possible, because if they are twisted at all then the module will not fit well in a 2HP space next to other modules.

Connect all the sleeve contacts (grounds; shown as pale orange-pink wire in the diagram) to each other. I suggest doing those first because these wires can fit comfortably under the other ones. I usually use bare copper wire for these connections because it's possible to thread a single long wire through all eight lugs, but doing that is somewhat fiddly and makes it necessary to carefully avoid contact with other things. It may not really be any easier than using several short pieces of insulated wire.

Connect a diode to the tip contact of each of the six jack sockets indicated. Note that the diodes are polarized, with a black band on the glass body indicating one end as special. That end is the *cathode*. The other end (the *anode*) of the diode must connect to the jack socket.

Connect one end of each resistor to ground. In principle they can connect to ground anywhere, but it's probably most convenient to connect them as shown, directly to the sleeve contacts of the output jacks.

Connect the diode cathodes and remaining ends of the resistors together in groups as shown, and those joined connections to the remaining two jack socket tip contacts. It is probably easiest to bend the wire component leads and use those to make the connections in a daisy-chain fashion, as shown by the grey wires in the diagram.

Connect the combined connection from each group to the normalling contact of the output jack socket for the *other* group, as shown by the red wires. These wires can connect to the chained component leads at any convenient points along the chains; it is not necessary to follow exactly the layout shown, although it may be a convenient one.

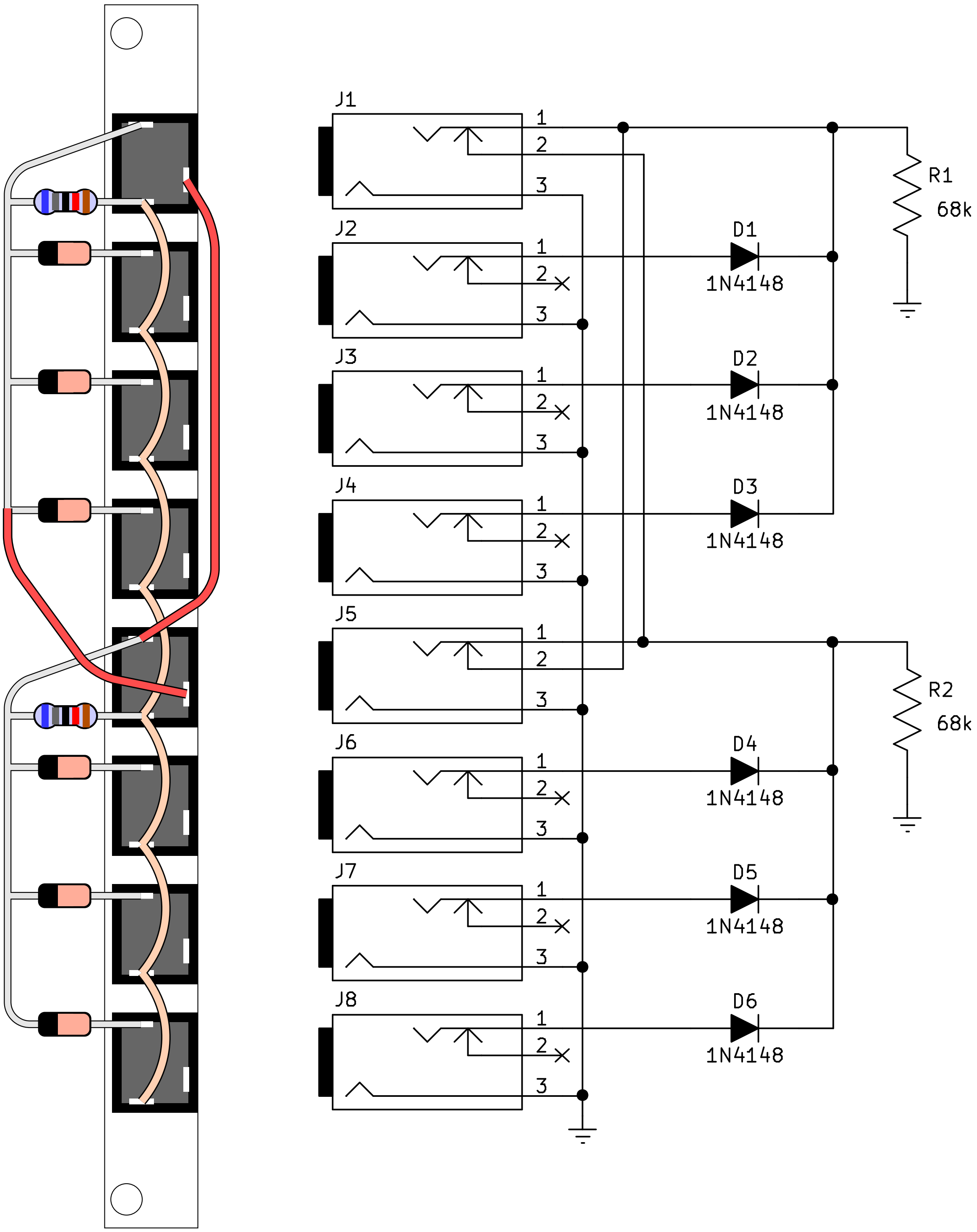


Figure 7: OR combiner schematic and wiring.

Fixed attenuator

It's usually a mistake to get hung up on "voltage ranges" of synthesizer modules, especially if you're going to put them in a spreadsheet, use them to compare modules or to decide what can patch into what, or attempt to measure voltages to undue precision. That's all the more true if you also insist on using "passive" modules whose poorly-controlled impedances will make voltages iffy anyway.

Nonetheless, people want to use "voltage ranges" and convert between them, and a fixed passive attenuator like this one may be useful for that. This circuit's basic function is to present at its output a fixed proportion like 50% of the voltage at its input. That could convert, for instance, a control voltage in the range 0–10V to one in the range 0–5V.

The front-panel connections are as shown in Figure 8. Depending on your needs, you could select the components to give four channels with the same attenuation, four different values, or even combine this with one of the other single-input/single-output projects described in subsequent chapters of these notes to have one or more channels of attenuation and one or more of other functions.

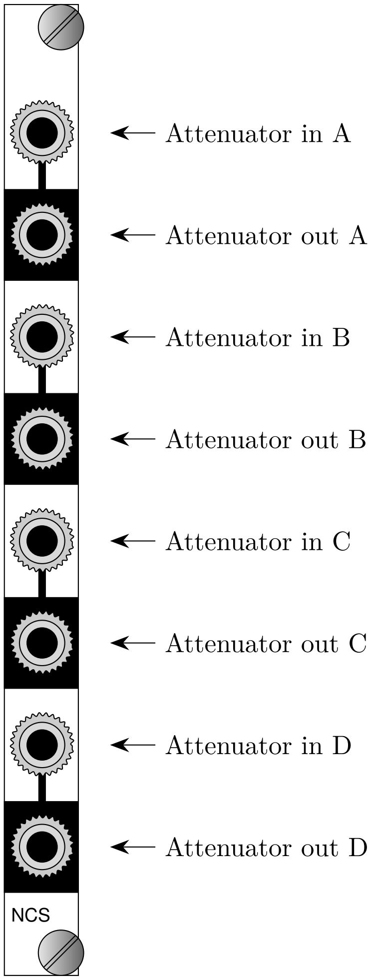


Figure 8: Attenuator connections.

Component selection

Each attenuator has two resistors in it; for the first channel they are R1 (connected between the tips of the input and output jacks) and R2 (connected from the tip of the output jack to ground). For the other channels they are respectively R3 and R4; R5 and R6; and R7 and R8. The resistors form a voltage divider, which sets the attenuation ratio. For instance, if you set the two resistors equal, the open-circuit output voltage would be half the input voltage.

However, the resistor value ratio is only a starting point, because in a real patch, the attenuator will be driving a module input which has an unknown input impedance, *typically* but often not *exactly* 100kΩ. Many module inputs with built-in attenuator knobs of their own will have input impedance that varies a little with the position of the knob. So if you're shooting for a specific attenuation ratio, you need to include in the calculation an estimate of the impedance the attenuator will be driving, and even then accept that the result may be only approximate.

Other issues worth bearing in mind are component tolerances, and that the input impedance of the attenuator will be at most the sum of R1 and R2 (possibly further reduced if the downstream input impedance is not significantly more than R2). That can cause the upstream output to produce an inaccurate voltage if its own impedance is too high. Also, if the downstream input has a non-zero open-circuit voltage, that can throw off the result.

Bearing in mind that for these reasons the ratios can only be approximate, Table 1 gives some suggested standard E12 resistor values for attenuation ratios that might be useful. For each pair of resistor values, there are three sets of columns showing the output voltage as a percentage of the input voltage, the attenuation in decibels, and the apparent input impedance rounded to the nearest kiloohm, on the assumption that the attenuator is driving an input with 10kΩ or 100kΩ impedance or an open circuit.

To use that table, choose a desired voltage ratio expressed as a percentage, or a desired amount of attenuation expressed in decibels; search the V/V or A column in the column set corresponding to your estimate of downstream input impedance (most likely 100kΩ) for the nearest match; and then read off the values of R1 and R2 in the first two columns. For example, suppose you want to convert a 0–8V "voltage range" to 0–5V when driving a module with a 100kΩ input. Calculating that 5V is 62.5% of 8V, you find 62.5 in the third column of the table (voltage ratio for 100kΩ downstream), and read off the resistor values R1=27kΩ, R2=82kΩ.

I generated the table by selecting E12 resistor values that would give reasonable input impedance and voltage ratios or decibel attenuation amounts I thought might be desirable for modular synth patches. To expand it for other values of the resistors R1 and R2, and other values of the impedance $\mathrm{R}_{\mathrm{out}}$ connected at the output, you can calculate the voltage proportion $V_{\mathrm{out}}/V_{\mathrm{in}}$, the input impedance R_{in}, and the attenuation A in decibels with the following formulas. For "open circuit" at the output, use $\mathrm{R}_{\mathrm{out}} = \infty$, $1/\infty = 0$.

$$\mathrm{R}_{\mathrm{x}} = \frac{1}{\frac{1}{\mathrm{R2}} + \frac{1}{\mathrm{R}_{\mathrm{out}}}} \qquad \mathrm{R}_{\mathrm{in}} = \mathrm{R1} + \mathrm{R}_{\mathrm{x}}$$

$$\frac{V_{\mathrm{out}}}{V_{\mathrm{in}}} = \frac{\mathrm{R}_{\mathrm{x}}}{\mathrm{R}_{\mathrm{in}}} \qquad A = -20 \log_{10} \frac{V_{\mathrm{out}}}{V_{\mathrm{in}}}$$

Building the module

To build a module with four fixed attenuators, you will need the panel PCB, eight jack sockets, eight resistors, and some wire. However, you might wish to combine this project with one of the other single-input/single-output functions described elsewhere in these notes, in which case you need two resistors per channel of attenuation and whatever other components are appropriate for the other channels. See the comments in the introduction regarding details of the panel, sockets, and wire.

Choose the resistor values as discussed in the previous section. The example values shown in the wiring diagram are selected to give (top to bottom) output of about 80%, 60%, 40%, and 20% of the input voltage, assuming a 100kΩ load.

Install the jack sockets in the panel PCB as shown in Figure 9, which is a view from the back of the module. Make sure the side you want to be at the front of the installed module (probably the "groups of two" side) really is facing outward, that is, away from you as you look at the back of the module. When viewed from the back, the mounting screw holes should be nearer the viewer's left, as shown in the diagram, to ensure that the panel will be right side up when completed. Try to get the jack socket bodies as straight as possible, because if they are twisted at all then the module will not fit well in a 2HP space next to other modules.

Connect all the sleeve contacts (grounds; shown as pale orange-pink wire in the diagram) to each other. I suggest doing those first because these wires can fit comfortably under the other ones. I usually use bare copper wire for these connections because it's possible to thread a single long wire through all eight lugs, but doing that is somewhat fiddly and makes it necessary to carefully avoid contact with other things. It may not really be any easier than using several short pieces of insulated wire.

Connect resistors to the tip and sleeve contacts of the jack sockets as shown. For each attenuation channel, the series resistor (R1) connects between the tips of the input and output jacks, and the parallel resistor (R2) connects from the tip of the output jack to any convenient grounding point; the sleeve of the output jack, as shown, is probably a good choice.

		$R_{\text{out}} = 100\text{k}\Omega$			R_{out} open			$R_{\text{out}} = 10\text{k}\Omega$		
R1 (kΩ)	R2 (kΩ)	V/V (%)	R_{in} (kΩ)	A (dB)	V/V (%)	R_{in} (kΩ)	A (dB)	V/V (%)	R_{in} (kΩ)	A (dB)
100	1	1.0	101	40.2	1.0	101	40.1	0.9	101	40.9
120	3.9	3.0	124	30.4	3.1	124	30.0	2.3	123	32.8
100	3.3	3.1	103	30.2	3.2	103	29.9	2.4	102	32.3
100	4.7	4.3	104	27.3	4.5	105	27.0	3.1	103	30.2
82	10	10.0	91	20.0	10.9	92	19.3	5.7	87	24.8
47	5.6	10.1	52	19.9	10.6	53	19.5	7.1	51	23.0
33	8.2	18.7	41	14.6	19.9	41	14.0	12.0	38	18.4
100	33	19.9	125	14.0	24.8	133	12.1	7.1	108	22.9
82	27	20.6	103	13.7	24.8	109	12.1	8.2	89	21.8
120	68	25.2	160	12.0	36.2	188	8.8	6.8	129	23.4
68	33	26.7	93	11.5	32.7	101	9.7	10.1	76	19.9
33	15	28.3	46	11.0	31.3	48	10.1	15.4	39	16.3
82	56	30.4	118	10.3	40.6	138	7.8	9.4	90	20.6
68	47	32.0	100	9.9	40.9	115	7.8	10.8	76	19.3
100	100	33.3	150	9.5	50.0	200	6.0	8.3	109	21.6
33	22	35.3	51	9.0	40.0	55	8.0	17.2	40	15.3
82	100	37.9	132	8.4	54.9	182	5.2	10.0	91	20.0
68	82	39.9	113	8.0	54.7	150	5.2	11.6	77	18.7
47	47	40.5	79	7.9	50.0	94	6.0	14.9	55	16.5
18	15	42.0	31	7.5	45.5	33	6.8	25.0	24	12.0
33	47	49.2	65	6.2	58.8	80	4.6	20.0	41	14.0
68	220	50.3	137	6.0	76.4	288	2.3	12.3	78	18.2
15	18	50.4	30	5.9	54.5	33	5.3	30.0	21	10.5
10	12	51.7	21	5.7	54.5	22	5.3	35.3	16	9.0
12	15	52.1	25	5.7	55.6	27	5.1	33.3	18	9.5
22	33	53.0	47	5.5	60.0	55	4.4	25.9	30	11.7
33	68	55.1	74	5.2	67.3	101	3.4	20.9	42	13.6
33	100	60.2	83	4.4	75.2	133	2.5	21.6	42	13.3
15	33	62.3	40	4.1	68.8	48	3.3	33.8	23	9.4
27	82	62.5	72	4.1	75.2	109	2.5	24.8	36	12.1
18	47	64.0	50	3.9	72.3	65	2.8	31.4	26	10.1
27	120	66.9	82	3.5	81.6	147	1.8	25.5	36	11.9
12	39	70.0	40	3.1	76.5	51	2.3	39.9	20	8.0
27	180	70.4	91	3.0	87.0	207	1.2	26.0	36	11.7
15	82	75.0	60	2.5	84.5	97	1.5	37.3	24	8.6
8.2	33	75.2	33	2.5	80.1	41	1.9	48.3	16	6.3
8.2	47	79.6	40	2.0	85.1	55	1.4	50.1	16	6.0
15	150	80.0	75	1.9	90.9	165	0.8	38.5	24	8.3
5.6	47	85.1	38	1.4	89.4	53	1.0	59.6	14	4.5
5.6	56	86.5	42	1.3	90.9	62	0.8	60.2	14	4.4
8.2	270	89.9	81	0.9	97.1	278	0.3	54.0	18	5.3
2.7	47	92.2	35	0.7	94.6	50	0.5	75.3	11	2.5
4.7	150	92.7	65	0.7	97.0	155	0.3	66.6	14	3.5
3.9	100	92.8	54	0.7	96.2	104	0.3	70.0	13	3.1
2.2	82	95.3	47	0.4	97.4	84	0.2	80.2	11	1.9
1	100	98.0	51	0.2	99.0	101	0.1	90.1	10	0.9

Table 1: Resistor values for the attenuator.

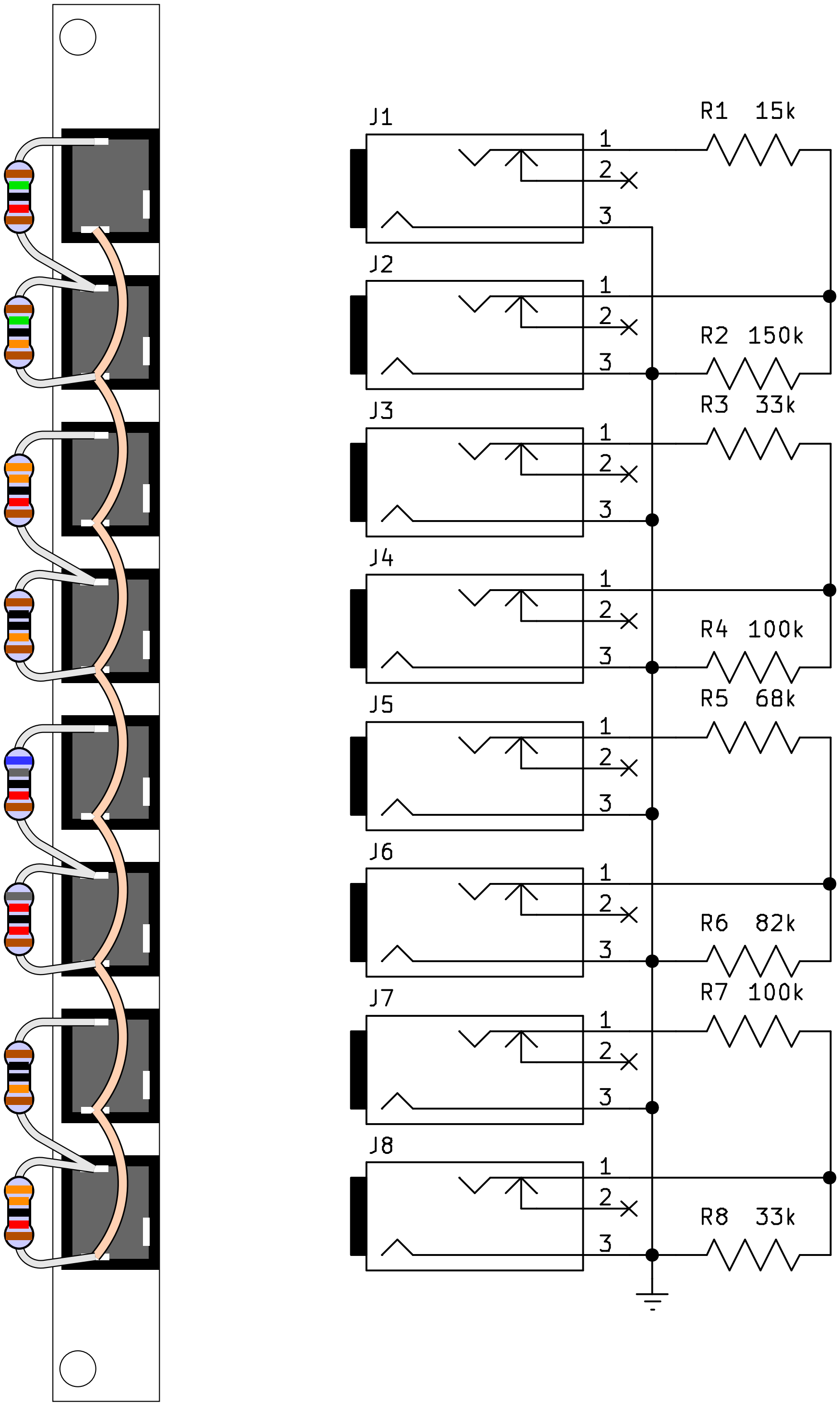


Figure 9: Attenuator schematic and wiring.

Low-pass filter/slew rate limiter

This basic circuit can be called a low-pass filter or slew rate limiter depending on cutoff frequency and whether it's used on audio or control signals. The front-panel connections are as shown in Figure 10. As with the other single-input/single-output projects described in these notes, you can build four of them into a single 2HP module, or combine channels of LPF with channels of other functions.

Component selection

These are single-pole (6dB/octave) low-pass filters with corner frequency given by the usual formula: $f = 1/2\pi RC$. When using the circuit as a slew rate limiter, the time constant is simply RC. So you can choose the resistor and capacitor values to give whatever frequency/time constant you want.

One caveat is that if the filter is driving an input with finite input impedance (like the typical 100kΩ), then the R value determining the frequency is properly the value of the resistor in the filter *in parallel with* the input impedance it's driving; so if the impedance of the downstream input is not large in comparison to the resistor in the filter, it will tend to pull the filter to a higher frequency. On the other hand, if the resistor value used in the filter is made small to avoid that effect, the input impedance of the filter will be low and may overload the output upstream. For these reasons I suggest keeping the resistor value between about 3kΩ and 30kΩ for best compatibility with Eurorack inputs and outputs. Then covering a wide range of audio and control-voltage frequencies implies a wide range of capacitors may be needed.

Table 2 gives some sample resistor and capacitor values for the filter, including the frequency and time constant values with 100kΩ and 10kΩ loads and into an open circuit. The table shows one decade of E6 standard capacitor values with 8.2kΩ, 10kΩ, and 12kΩ resistors, which are the three E12 standard resistors closest to my target of 10kΩ. For frequencies in other decades, just multiply or divide the capacitor value by the appropriate power of ten. For example, to aim for a corner frequency of 800Hz when

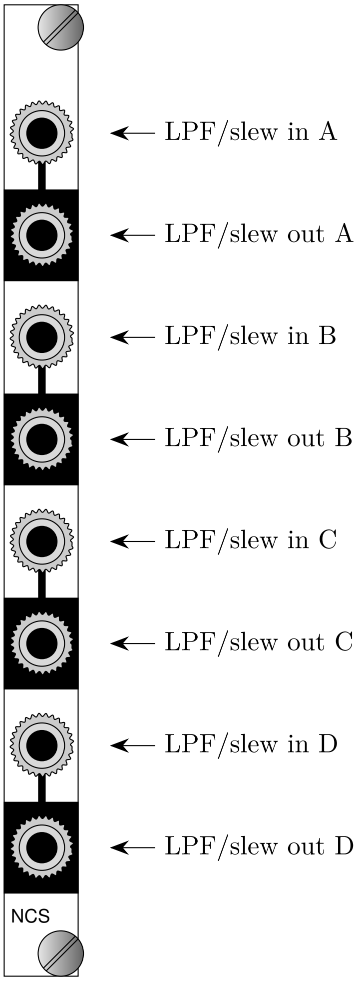


Figure 10: LPF/slew connections.

		$R_{\text{out}} = 100\text{k}\Omega$		R_{out} open		$R_{\text{out}} = 10\text{k}\Omega$	
R	C	f	τ	f	τ	f	τ
(kΩ)	(μF)	(Hz)	(ms)	(Hz)	(ms)	(Hz)	(ms)
12	6.8	2.2	73	2.0	82	4.3	37
10	6.8	2.6	62	2.3	68	4.7	34
8.2	6.8	3.1	52	2.8	56	5.2	31
12	4.7	3.2	50	2.8	56	6.2	26
10	4.7	3.7	43	3.4	47	6.8	24
8.2	4.7	4.5	36	4.1	38	7.5	21
12	3.3	4.5	35	4.0	40	8.8	18
10	3.3	5.3	30	4.8	33	9.6	16
8.2	3.3	6.4	25	5.9	27	11	15
12	2.2	6.8	24	6.0	26	13	12
10	2.2	8.0	20	7.2	22	14	11
8.2	2.2	9.6	17	8.8	18	16	9.9
12	1.5	9.9	16	8.8	18	20	8.2
10	1.5	12	14	11	15	21	7.5
8.2	1.5	14	11	13	12	24	6.8
12	1.0	15	11	13	12	29	5.5
10	1.0	18	9.1	16	10	32	5.0
8.2	1.0	21	7.6	19	8.2	35	4.5

Table 2: Component values for low-pass and high-pass filters.

driving a 100kΩ input, the relevant line of the table specifies 10kΩ and 2.2μF for 8.0Hz, and then because the target frequency is 100 times that, we divide the capacitor value by 100. The resistor and capacitor values for 800Hz would be 10kΩ and 0.022μF.

On capacitors: I suggest NP0 or C0G ceramic capacitors for the really small values (highest frequencies), not X7R or similar because of the distortion they can introduce; plastic film (most likely polyester) for low to medium audio frequencies; and aluminum electrolytic when necessary to get the high values for control-voltage slew limiting. Capacitors should be rated for at least about 15V.

Electrolytics are likely to be polarized, and in that case, they shouldn't be used for negative voltages and you should add a diode to the circuit, as discussed in the construction section below, to make *sure* negative voltage isn't applied to the capacitor. If you need really long time constants and also compatibility with negative voltages, then you may need to find non-polarized electrolytics, or just use really big film capacitors. Very high-valued ceramic capacitors are likely to be ferroelectric ceramic (X7R and similar) and may not give good results.

Building the module

To build a module with four fixed LPFs, you will need the panel PCB, eight jack sockets, four resistors, four capacitors, and some wire. However, you might wish to combine this project with one of the other single-input/single-output functions described elsewhere in these notes, in which case you need a resistor and capacitor for each LPF channel and whatever other components are appropriate for the other channels. You will also need a general-purpose diode (such as 1N4148 type) for each *polarized electrolytic* capacitor you use. See the comments in the introduction regarding details of the panel, sockets, and wire.

Choose the resistor values as discussed in the previous section. The example values shown in the wiring diagram are selected to give a range of different corner frequencies.

If you are using polarized electrolytic capacitors, as might be needed to achieve the slowest slew rates on control voltages, then you should add a diode across each one to prevent applying reverse voltage. In that case the module will not work on negative voltage inputs.

Install the jack sockets in the panel PCB as shown in Figure 11, which is a view from the back of the module. Make sure the side you want to be at the front of the installed module (probably the “groups of two” side) really is facing outward, that is, away from you as you look at the back of the module. When viewed from the back, the mounting screw holes should be nearer the viewer’s left, as shown in the diagram, to ensure that the panel will be right side up when completed. Try to get the jack socket bodies as straight as possible, because if they are twisted at all then the module will not fit well in a 2HP space next to other modules.

Connect all the sleeve contacts (grounds; shown as pale orange-pink wire in the diagram) to each other. I suggest doing those first because these wires can fit comfortably under the other ones. I usually use bare copper wire for these connections because it’s possible to thread a single long wire through all eight lugs, but doing that is somewhat fiddly and makes it necessary to carefully avoid contact with other things. It may not really be any easier than using several short pieces of insulated wire.

Connect the resistors from the tip of the input jack socket to the tip of the output jack socket for each channel. Connect the capacitors across the tip and sleeve contacts of the output jack socket for each channel. If you are using a polarized capacitor, then as shown in the bottom channel in the drawing connect the negative side of the capacitor, which is usually marked with a stripe, to the sleeve; and connect a diode across the tip and sleeve as well. The diode is polarized and will have one end (the *cathode*) marked with a stripe; that end should connect to the tip contact.

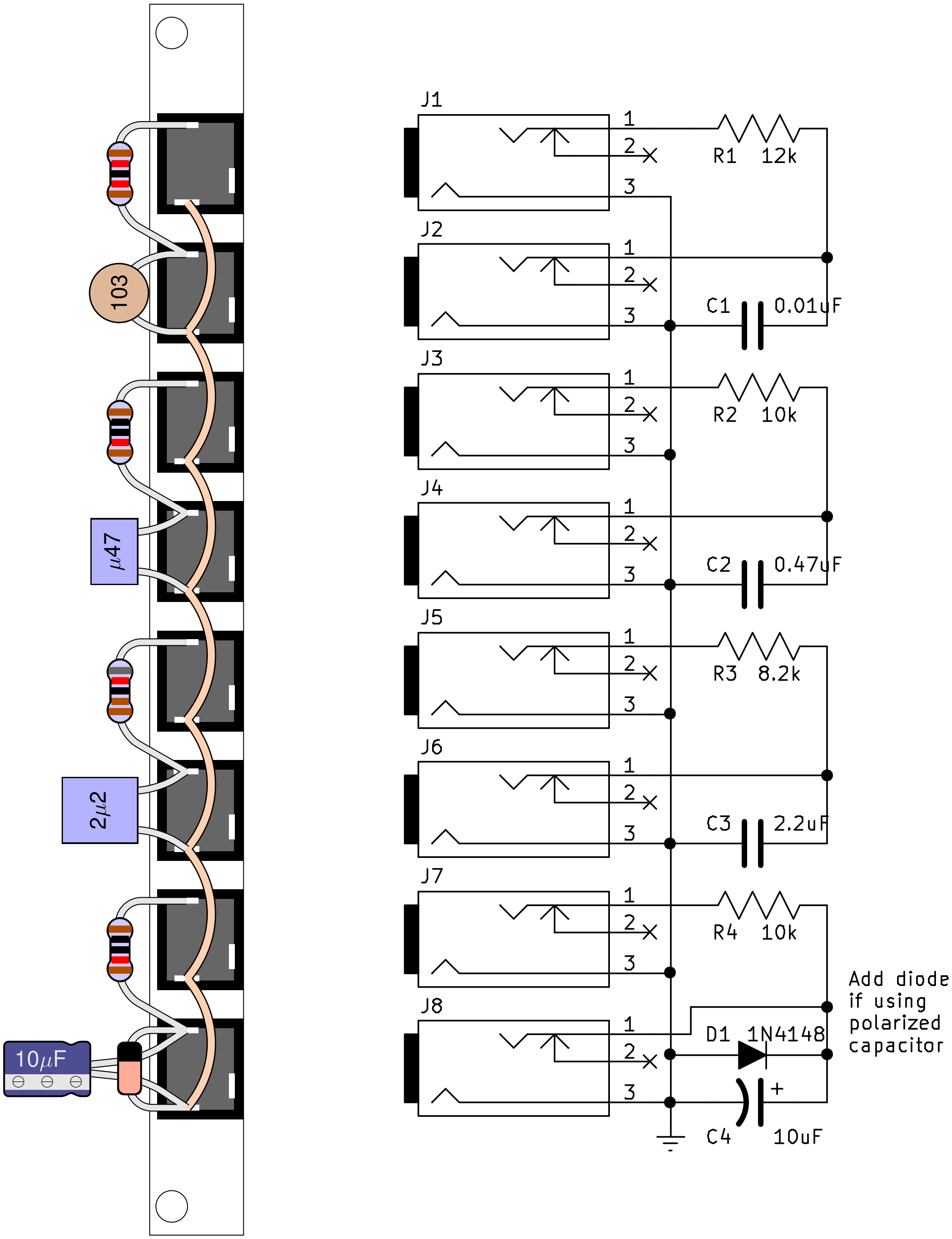


Figure 11: LPF/slew schematic and wiring.

High pass/DC blocker/gate to trigger

This simple unpowered high-pass filter can be built with an audio-frequency cutoff to cut bass; with a lower cutoff to remove DC offsets from audio signals; or with a slight modification to remove negative pulses, it can convert gate control voltages into trigger control voltages.

The front-panel connections are as shown in Figure 12. As with the other single-input/single-output projects described in these notes, you can build four of them into a single 2HP module, or combine channels of HPF with channels of other functions.

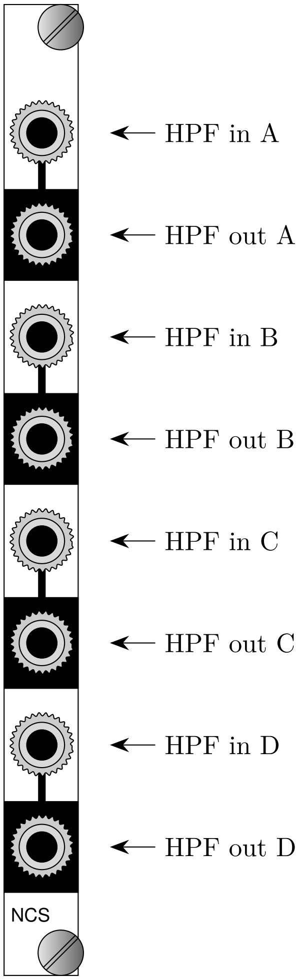


Figure 12: HPF connections.

Component selection

These are single-pole (6dB/octave) high-pass filters with corner frequency given by the usual formula: $f = 1/2\pi RC$. This is the same formula that applies to the LPF design of the previous chapter, and the same considerations apply with respect to the effect of the input impedance of the downstream module, so see the "Component selection" section of that project (page 20) for instructions on choosing a resistor and capacitor value for use with audio cutoff frequencies.

The design recommendations for the LPF emphasize keeping the resistor value near 10kΩ to reduce the effect of changes in the downstream impedance on the cutoff value. If you will be building the HPF circuit with a low cutoff for DC blocking, then it may be more important to achieve the low cutoff with convenient component values, and without polarized capacitors, than to keep the cutoff frequency stable. For DC blocking on Eurorack audio, I would use instead a resistor value of 100kΩ and a 4.7μF film capacitor, which is the largest film capacitor I normally keep on hand. That should keep the cutoff below 1Hz even when patched into a Eurorack input with lower than standard impedance. Film capacitors that size are a bit expensive and it would be reasonable to substitue one a little smaller if desired.

For gate to trigger, with a diode, the resistor and capacitor values can vary depending on the length of trigger desired, but my suggestion of convenient values would be 10kΩ and 0.1μF, which give a 1ms time constant into an open circuit. The "length" of the trigger will be a bit more complicated than just equal to the time constant because of the pulse's exponentially decaying shape, but it will still be on the order of 1ms and about right for most applications that call for a trigger pulse.

I suggest NP0 or C0G ceramic capacitors for the really small values (highest frequencies) when used for audio. You could get away with using an X7R or similar capacitor in a gate to trigger converter. For lower frequencies, I would suggest plastic film. For the lowest frequencies I would prefer to start increasing the resistor value rather than switching to electrolytic, but an unpolarized electrolytic would be reasonable as well. I would not use a polarized electrolytic capacitor in this circuit.

Building the module

To build a module with four fixed HPFs or DC blockers, you will need the panel PCB, eight jack sockets, four resistors, four capacitors, and some wire. However, you might wish to combine this project with one of the other single-input/single-output functions described elsewhere in these notes, in which case you need a resistor and capacitor for each HPF channel and whatever other components are appropriate for the other channels. You will also need to add a general-purpose diode (such as 1N4148 type) for each channel that you will configure as a gate to trigger converter. See the comments in the introduction regarding details of the panel, sockets, and wire.

Choose the resistor values as discussed in the previous section. The example values shown in the wiring diagram are selected to give a range of different corner frequencies.

Install the jack sockets in the panel PCB as shown in Figure 13, which is a view from the back of the module. Make sure the side you want to be at the front of the installed module (probably the "groups of two" side) really is facing outward, that is, away from you as you look at the back of the module. When viewed from the back, the mounting screw holes should be nearer the viewer's left, as shown in the diagram, to ensure that the panel will be right side up when completed. Try to get the jack socket bodies as straight as possible, because if they are twisted at all then the module will not fit well in a 2HP space next to other modules.

The component values shown in the schematic and wiring diagram correspond to (from top to bottom) 2.1kHz corner frequency; 100Hz; DC block (corner below 1Hz); and gate to trigger with 1ms time constant.

Connect all the sleeve contacts (grounds; shown as pale orange-pink wire in the diagram) to each other. I suggest doing those first because these wires can fit comfortably under the other ones. I usually use bare copper wire for these connections because it's possible to thread a single long wire through all eight lugs, but doing that is somewhat fiddly and makes it necessary to carefully avoid contact with other things. It may not really be any easier than using several short pieces of insulated wire.

Connect the capacitors from the tip of the input jack socket to the tip of the output jack socket for each channel. Connect the resistors across the tip and sleeve contacts of the output jack socket for each channel. For any channel that will be used as a gate to trigger converter, connect a diode across the tip and sleeve contacts of the output jack. The diode is polarized and will have one end (the *cathode*) marked with a stripe; that end should connect to the tip contact.

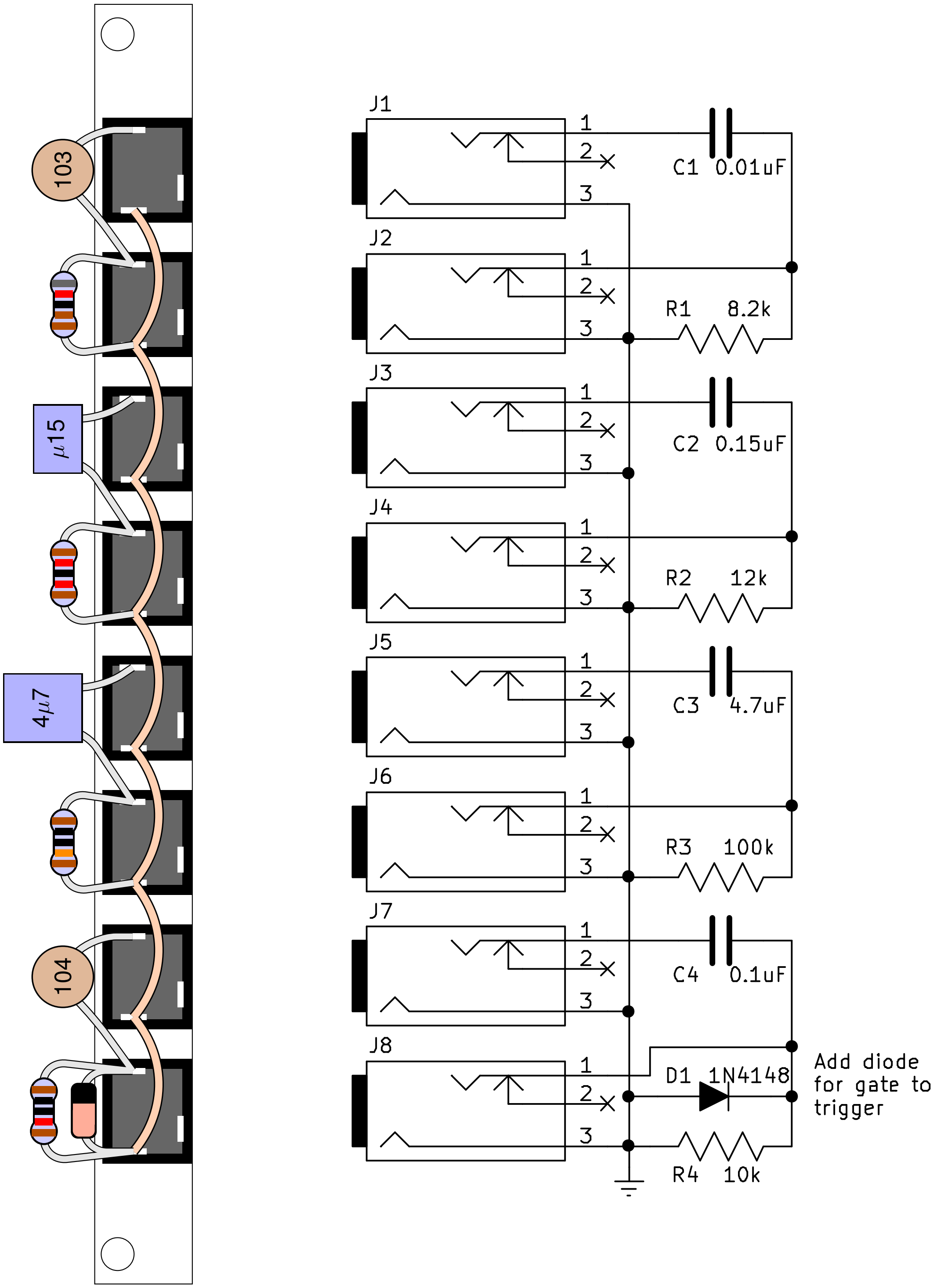


Figure 13: HPF/DC blocker/gate to trigger schematic and wiring.

Envelope follower

This envelope follower converts an audio signal to a control voltage representing the peak amplitude of the audio. The front-panel connections are as shown in Figure 14. As with the other single-input/single-output projects described in these notes, you can build four of them into a single 2HP module, or combine channels of envelope follower with channels of other functions.

Be aware that this is an unpowered envelope follower, and the diode in the circuit will eat up a little bit of the signal voltage (roughly 0.6V or 0.7V with a common silicon diode like 1N4148). Typical Eurorack audio levels are high enough that that should be no problem, but it does mean that the follower will not track amplitude all the way down into the decay tails of sounds that go significantly below their peak levels. You can reduce the voltage loss by substituting a germanium or Schottky diode, but this effect will always exist to some extent with an unpowered envelope follower.

It's also worth noting that this circuit will pass DC; if your signal contains a significant DC offset that will throw the results off. If working with such signals you might find the DC blocker in the previous chapter useful; you could even build the DC blocker and envelope follower into the same module and normal the envelope follower's input to the DC blocker's output. There's some signal loss from doing that but overall it should still work as well as unpowered modules usually do.

I'm recommending a 100kΩ resistor and 1μF capacitor value for this circuit; these will give a time constant of about 50ms when driving a typical 100kΩ Eurorack input. That should be plenty for most envelope-following applications. You can reduce either component value (I would reduce the resistor first to reduce the dependence on the downstream input impedance) for faster response, at the cost of a less smooth output when following low-frequency sounds. I would only use a film capacitor because the capacitance values, higher or lower, that would make a different type appropriate, are unlikely to be relevant here.

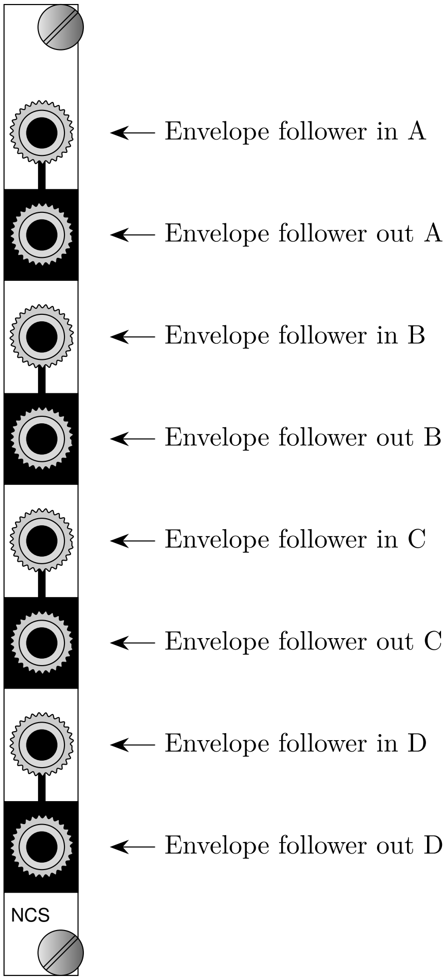


Figure 14: Envelope follower connections.

Building the module

To build a module with four envelope followers, you will need the panel PCB, eight jack sockets, four 100kΩ resistors, four 1μF film capacitors, four diodes (see comments above regarding type), and some wire. However, you might wish to combine this project with one of the other single-input/single-output functions described elsewhere in these notes, in which case you need a resistor, capacitor, and diode for each envelope follower channel and whatever other components are appropriate for the other channels. See the comments in the introduction regarding details of the panel, sockets, and wire.

Install the jack sockets in the panel PCB as shown in Figure 15, which is a view from the back of the module. Make sure the side you want to be at the front of the installed module (probably the "groups of two" side) really is facing outward, that is, away from you as you look at the back of the module. When viewed from the back, the mounting screw holes should be nearer the viewer's left, as shown in the diagram, to ensure that the panel will be right side up when completed. Try to get the jack socket bodies as straight as possible, because if they are twisted at all then the module will not fit well in a 2HP space next to other modules.

Connect all the sleeve contacts (grounds; shown as pale orange-pink wire in the diagram) to each other. I suggest doing those first because these wires can fit comfortably under the other ones. I usually use bare copper wire for these connections because it's possible to thread a single long wire through all eight lugs, but doing that is somewhat fiddly and makes it necessary to carefully avoid contact with other things. It may not really be any easier than using several short pieces of insulated wire.

Connect a capacitor and a resistor between the tip and sleeve contacts of each of the output jack sockets. Connect a diode between the tip of the input jack and the tip of the output jack for each channel. The diodes are polarized and will have one end (the *cathode*) marked with a stripe; that end should connect to the output tip.

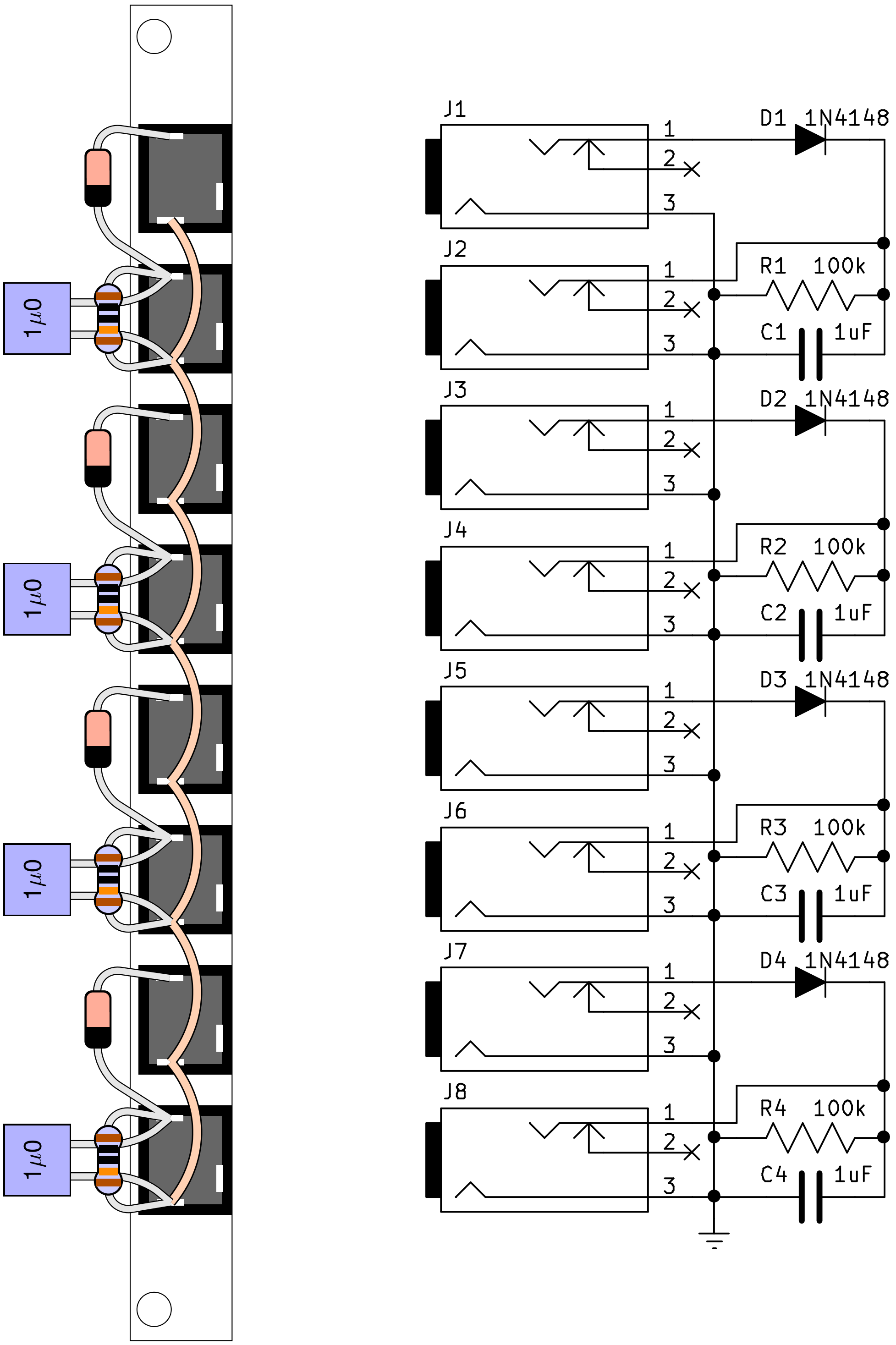
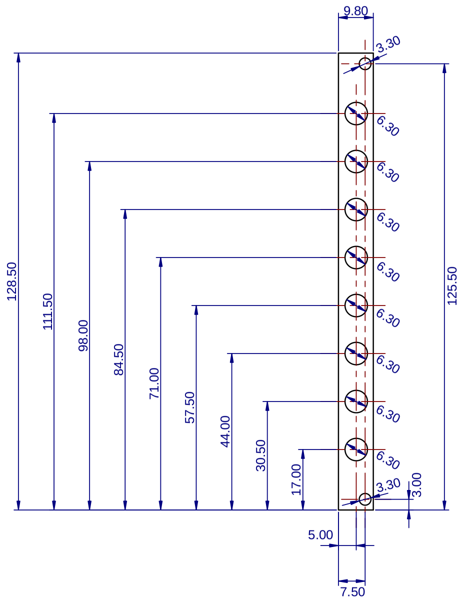


Figure 15: Envelope follower schematic and wiring.



NOTES

1: All dimensions are millimetres with tolerance +/- 0.10mm.
Do not scale off drawing.

2: Material is circuit board fibreglass, 2.00mm thick. Overall dimensions are 128.50mm by 9.80mm, per Doepfer spec for a 2HP Eurorack synthesizer module.

3: 1oz copper and solder mask all over both sides. All holes plated through. Dimensions are finished sizes.

Passive multiple panel	
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