MSK 003 Passive ring modulator

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General notes

This is documentation for the MSK 003 Passive Ring Modulator. It's a very simple synthesizer module and probably doesn't need so much documentation, but I am working on some more complicated designs and using this document as a testbed for the software, visual design, and other things that I will use in the bigger projects. My hope is to build up a library of well-documented and nicely-packaged module designs that people can use.

The MSK 003 is a basic traditional ring mod circuit suitable for use with most modular synthesizers. Two of them, built with expensive miniature transformers, will fit nicely into 4HP of Eurorack space. Because it is signal-powered (which is what synthesizer people call "passive," despite the presence of diodes in the circuit), it has no power supply requirement and so with an appropriate panel it would be at home in a ±15V-powered system just as well as ±12V Eurorack.

I designed the circuit board for this using gEDA tools, but I have subsequently switched all my electronic design work to Kicad. That presents something of a dilemma: I would like to distribute this design, but I don't want to distribute it in a format I no longer use and for which I don't want to offer support. It would be no big deal to just re-draw the schematic and board in Kicad, but I also don't want to distribute a PCB layout for others to use that I cannot vouch for by actually having had it fabbed and assembling it myself. And I don't really need *more* passive ring modulators now that I have built two, and I don't want to be in the business of building them for sale either—so building more and then using or selling them, just to test the design, doesn't seem like a fun idea.

The solution I have chosen is that I will distribute the board design Gerber files that I made with gEDA. These are exactly the same ones I used to have my boards fabbed by OSH Park; I can vouch for them. If anyone wants to have boards fabbed that exactly match mine, they can. I will distribute the schematic (which came from gEDA) only as part of this PDF. I won't distribute the editable gEDA files. Some day if I do decide to build more passive ring modulators, I'll redraw the design with Kicad and distribute the editable Kicad files at that time. This is such a simple circuit that anyone wanting to modify it should have no trouble just redrawing it from scratch anyway.

This package

You should have received this as a ZIP file containing:

- This PDF file.
- A Schaeffer "Front Panel Designer" `.fpd` file for a Eurorack 4HP front panel capable of accommodating two MSK 003 boards.
- Various Gerber `.gbr` and drill machine `.cnc` files that may be used to manufacture boards. These were generated by gEDA PCB on its default setting and are the exact files I used to have my boards manufactured at OSH Park. Most PCB fabs can probably read them.

Diodes

The heart of a ring modulator is the titular *ring* of four diodes. Diodes are characterized by a parameter called *forward voltage*; in a ring modulator, higher forward voltages mean higher signal levels are necessary and there will be more tendancy for the carrier to bleed into the output. Mismatches between the diodes will also cause carrier bleed and harm the shape of the output signal in more complicated ways. A small amount of carrier bleed is valued as part of the unique sound of audio diode ring modulation, but it is still customary to try to keep it small.

So the ring diodes should ideally have low forward voltages, but it is more important that their forward voltages should match each other as well as possible. There are basically three types you might reasonably use:

- Germanium, such as 1N695. These are the most expensive and the most traditional. They were developed earlier and so are associated with "vintage" ring modulation. Lowest forward voltage, but the forward voltage varies a lot between individual diodes, so it is desirable to hand-match them.

- Silicon Schottky type, such as SB130. Usually intermediate in price and forward voltage; but normally designed for higher power levels than are typical in an audio ring modulator, and that may have an effect on the sound.

- Plain silicon, such as 1N4148. Highest forward voltage, lowest price. Nowadays, the quality control on silicon diodes is very good and hand-matching is unlikely to be necessary. You would normally want a "switching" type of diode rather than a "rectifier."

In my own construction I used 1N695 germanium diodes that I bought from Small Bear Electronics.* I bought eight, and used the diode test feature on a DMM to pick out four with low and well-matched forward voltages for one of the ring mods. The remaining four went into the other. So I have a choice between a tightly matched and loosely-matched modulator. To be honest, I can't really hear a difference between the two anyway. I may have put in more effort than was necessary.

Almost any kind of diode should be usable, and the spaces for the diodes on the PCB are deliberately oversize to accomodate larger packages.

Transformers

The transformers are as important to the classic ring mod sound as are the diodes. Transformers for a diode ring modulator should be high impedance, with centre taps well-centred on the diode side, and appropriate frequency and power ratings. I used Triad SP-66 transformers, which are nearly identical to Tamura MET-09. These are very small (nice for a 4HP module) and expensive (I paid £14.16 each to Farnell, plus European VAT). They are basically US military-specification transformers, though these particular part numbers may actually be commercial-grade versions.

The transformers fit in what I call a DIP-6 footprint, which is two rows of three pins, 0.1 inch between the pins in a row and 0.3 inches between the rows—just like an eight-pin DIP cut down to six pins. They are rated for frequencies from 300Hz to 100kHz, with 10kΩ impedance on both sides.

Substituting transformers with somewhat different impedance should be fine if it's at least a few kΩ. If you can find 15kΩ or 20kΩ that may actually be better than 10kΩ. Cheaper transformers will usually have narrower frequency response, possibly much narrower, and they may not fit in the footprints of my PCB design. If the primary and secondary impedances are not the same, they should be arranged symmetrically, with the higher impedances facing the diodes on both input and output. Order of magnitude impedance differences (such as 600Ω on one side, 10kΩ on the other) are probably not appropriate for this circuit.

I found out, belatedly after having the PCBs fabricated, that although the SP-66 transformers claim to be symmetric in terms of impedance, their windings are not identical and differ by DC resistance. So I built my modulators with the higher-resistance "secondary" windings facing the diodes, which meant mounting the "output"-side transformer (Z connection) backwards relative to the markings on the PCB. Note that because of the symmetry of the circuit, one could just as well say that Z is the input and X is the output, so I wanted to keep everything as symmetric as possible.

Jacks

The PCB was designed for CUI Inc. MJ-3536 jacks, which are 1/8″ mono jacks typical of those used for Eurorack. In the Eurorack module the board is designed to mount perpendicular to the front panel, using the jacks for support. One could also mount it using the four mounting holes I have provided, and run wires from the jack connections on the board to jacks of any kind, for instance to make it work in some other format.

At the time I first designed the board I had a lot of MJ-3536 jacks on hand which I'd bought from Digi-Key, and I planned to use them. But then I moved to Denmark, used up most of my MJ-3536 jacks in another project, and found they were much harder to source in Europe than I had expected.† I ended up using Lumberg 1503 12 jacks on one of my boards, which are nearly identical (made to the same Japanese industry standard as the CUI jacks) but the Lumberg jacks have their rear legs slightly closer to the front than is the case for the MJ-3536. Fortunately, the holes in the board are big enough to accommodate either type of jack with some minor bending of the legs—a side effect of the fact that I

*http://smallbear-electronics.mybigcommerce.com/

†Digi-Key will ship to Europe, but will not collect the VAT, requiring me to pay it and a handling fee when the package arrives, in a prohibitively complicated way.

made the holes circular instead of plated slots because OSH Park cannot reliably manufacture plated slots nor gEDA specify them.

PCBs

The enclosed PCB design is a basic two-layer board with top and bottom ground planes. There shouldn't be anything terribly difficult about getting it fabricated by OSH Park or any other contractor. The circuit could, of course, also be built on stripboard, with point-to-point wiring, or by any other method. I bothered to have PCBs made despite that not necessarily being the easiest or cheapest way to do it, because I wanted to try out OSH Park's service with something small before risking it on a bigger project.

The PCB is 2.0″×1.5″, or 50.8mm×38.1mm. That means that in Eurorack, two of the boards can fit one above the other to make a vertical "dual" ring modulator module (and that is how I built mine) and the case needs to be at least about 40mm deep for the module to fit comfortably.

Panel and mounting

The enclosed panel design is compatible with Eurorack (4HP for a dual module) and Schaeffer AG's manufacturing service. Front Panel Express is the US arm of the same business and should also be able to use this design. There are plenty of other options for making a panel and this one is not necessarily the cheapest or best, but the result is very pretty, anyway. I used 2.0mm anodized aluminum. The jacks I used will not work well with anything thicker.

Because of the symmetry of the circuit, one could mount the board on either side of the jacks with basically identical results. Swapping between the two configurations, or swapping input and output, has the effect of inverting the carrier, which could conceivably make a difference if the same carrier signal is also used for other, interacting, parts of a patch, or if both carrier and signal are asymmetric. I mounted mine with the board on the right, which places J1 at the top.

Future enhancements

If I ever make more of these, then as well as redrawing it in Kicad I will probably change the PCB design a little to add discrete-wire pads for the tip and switch contacts on the jacks. In the current version the switching contacts just go to ground, but breaking them out into pads would allow for the possibility of normalling them with external wiring. I'll probably also add alternate footprints for the transformers and maybe even the jacks, to allow for more parts substitutions.

However, I don't have any immediate need for more passive ring modulators, and I don't want to distribute a design for others to use that I cannot vouch for by having built and tested it myself. So it may be a long time before I actually do publish a revised version of the board.

Use and contact information

The basic diode ring circuit is well known, and is the subject of a long-expired US patent. I cannot claim that to be original. This PCB design is original with me, but quite straightforward; lots of other people have done nearly identical things. I am happy to have people build and modify this design *even commercially* without further permission, but I want to be credited as the designer of whichever parts of my work you use.

I'm posting this and other electronics projects at `http://ansuz.sooke.bc.ca/electronics.php`. That would be a good place to look for updated versions or other related material. My Soundcloud account, which usually includes tracks recorded with this and other homemade electronics, is at `https://soundcloud.com/matt-skala/`. I can be found on the Muff Wiggler Forum as "mskala," but although others are welcome to do so, I don't plan to host build threads for this or my other projects there.

Email should be sent to `mskala@ansuz.sooke.bc.ca`.

Safety and other warnings

I offer no warranties whatsoever regarding these instructions and you follow them at your own risk.

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.

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; however, no stranded wire is involved in this particular module's construction when built as described anyway.

This module involves no particularly high impedances, and there should be no need to remove traditional or "no-clean" fluxes that are not water-soluble, unless you wish to remove them for cosmetic reasons.

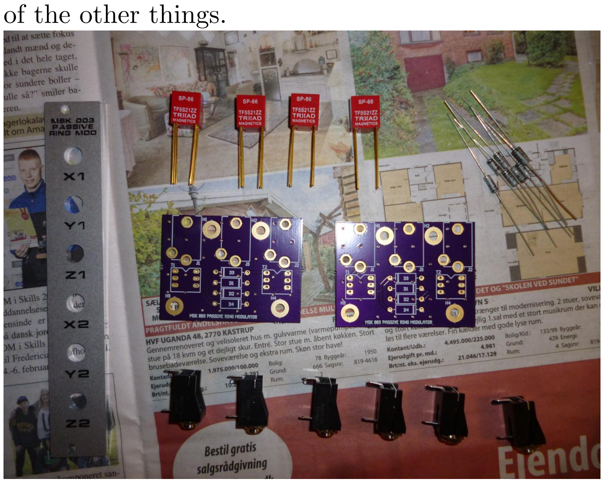
Since this module is powered entirely by its very low input signals, there is no significant shock hazard related to this module in particular, but it may often be used in combination with other products that do contain dangerous voltages or currents, so take appropriate care.

Building your own electronic equipment is seldom cheaper than buying equivalent commercial products, due to commercial economies of scale from which you as small-scale home builder cannot benefit. If you think getting into DIY construction is a way to save money, you will probably be disappointed.

Selling electronic devices you have constructed, even on a very small scale, may subject you to complicated and expensive legal obligations regarding such things as safety testing, waste disposal, electromagnetic interference, and so on, depending on where you and your customers live.

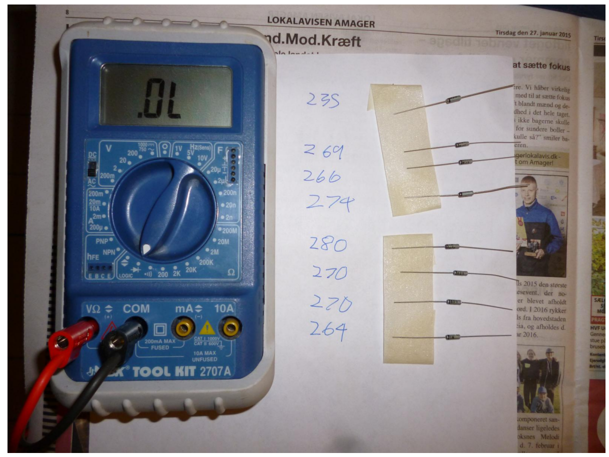
Build step-by-step

Gather together all the parts you will need. Each ring modulator requires four diodes (see comments earlier about choosing the diodes), three jacks, two transformers, and a circuit board. I was building a dual-modulator module, so as seen in the photo, I also have one dual front panel and double quantities of the other things.



Diode matching is optional, depending on how fussy you are and what kind of diodes you are using. I used the forward voltage test range on a digital multimeter to measure the forward voltages of all the diodes before choosing which would go onto which board. Numbers shown are in millivolts. I recommend the technique shown of putting sticky tape sticky side up on a piece of paper and sticking the diodes to it next to their measurement numbers.

Germanium diode forward voltages are temperature sensitive. To get accurate matching, make sure your diodes are all at the same stable room temperature (i.e. not immediately unpacked from a shipping container that has been in a chilly airplane cargo hold); don't run your soldering ventilation fan during this step; and handle the diodes by the ends of their legs, not their bodies, to avoid heating them with your fingers.

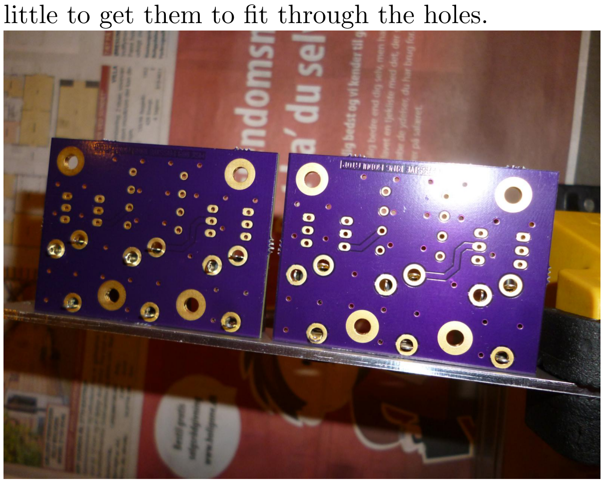


Boards from OSH Park and most other fabricators have protruding scars on the edges from where the boards were joined to the larger panel and then snapped off. Especially with the substitution on the jacks, there is little or no clearance between the edge of the board and the back of the front panel, so I had to file down the manufacturing scars on that edge to get a good fit.

Assemble the jacks to the front panel, using their included knurled nuts. Many people try to find or make special drivers to tighten these nuts without danger of scratching the panel, but I usually feel it's sufficient to just tighten them with my fingers. This step is first because there's a lot of slop or tolerance in the way the jacks are soldered to the PCBs, and it's important to do that in such a way that the jacks will line up with the holes in the panel and the PCBs and panel will not interfere with each other.

In this photo, the three jacks on the left are CUI jacks and the three on the right are Lumberg. You can spot minor differences: compared to the CUI jacks, the Lumberg jacks have slightly wider knurled nuts, slightly less deep bodies, no holes in the switching contact legs at the side, and slightly larger holes in the other two legs.

Place the PCBs such that the jack legs fit into their appropriate holes. Because of the tight clearances, jack substitution, and so on, I found that the PCBs held firmly by friction in the proper orientation, and didn't need additional fastening; but if they are loose, improvise something with tape or similar to hold them in place for soldering. In the case of the Lumberg jacks I also had to bend the back legs a little to get them to fit through the holes.



Solder the jacks and place the diodes. Note that diodes are polarized components. One end of each diode will be marked, usually with a stripe around the cylindrical body of the component. That end is the cathode, and it should be placed to match the stripe marked on the circuit board silk-screen. They alternate, as seen in this photo. However, in a diode ring modulator all that really matters is that the diodes form a ring—not whether it is clockwise or counterclockwise—so if your diodes are marked in some unusual way (as is possible with vintage germanium), it should be okay to make them alternate even if you are not certain which end is the cathode.

Germanium semiconductors can be damaged by overheating during soldering. Use a heat sink if you are concerned, and try to solder them quickly without excessive use of heat. I didn't use a heat sink, and my diodes appear to be unharmed.

Solder the diodes and place the transformers. See comments about transformers in the notes earlier. *Notwithstanding the markings on the board*, I soldered my transformers as shown, with the “secondary” side, which has higher DC resistance, closest to the diodes on both input and output. As a result the markings on the transformers show the front on one side and the back on the other. This was to ensure electrical symmetry. It was an issue I found out about upon re-reading the specification sheets in the time between when I sent the board designs to the fab and when they came back.

Here is the finished module:

An audio demonstration of what it sounds like is on Soundcloud at `https://soundcloud.com/matt-skala/ring-modulator-test`.

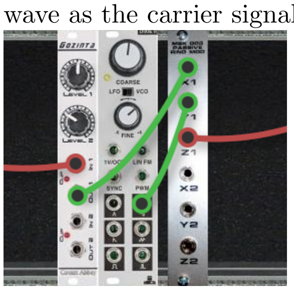
Patch ideas

Shortly before I moved to Denmark I read a Web page that explained how to make traditional Danish stinging-nettle liquor. At the end it said that, in addition to drinking it, you could use the result in cooking "wherever you would normally use stinging nettles." I would not normally cook with stinging nettles at all! So that advice was either less useful than it could have been, or more honest than the writer intended.

You can, similarly, use the MSK 003 in a synthesizer patch wherever you would normally use a ring modulator. But here are some ideas on where that might be.

Generate a bell-like timbre with two sine waves. This is the most basic ring modulator patch.

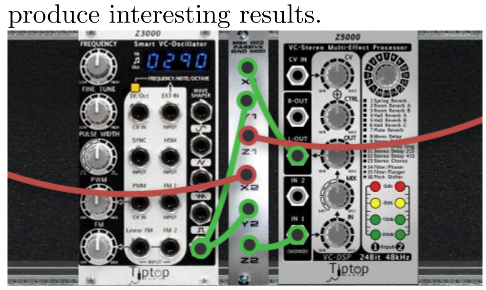
When you have a ring modulator, EU regulations require you at some point to hook up a microphone and say "Exterminate! Exterminate!" Folklore holds that the original BBC Dalek effect used a germanium diode ring modulator with a tape loop of a 30Hz sine wave as the carrier signal.

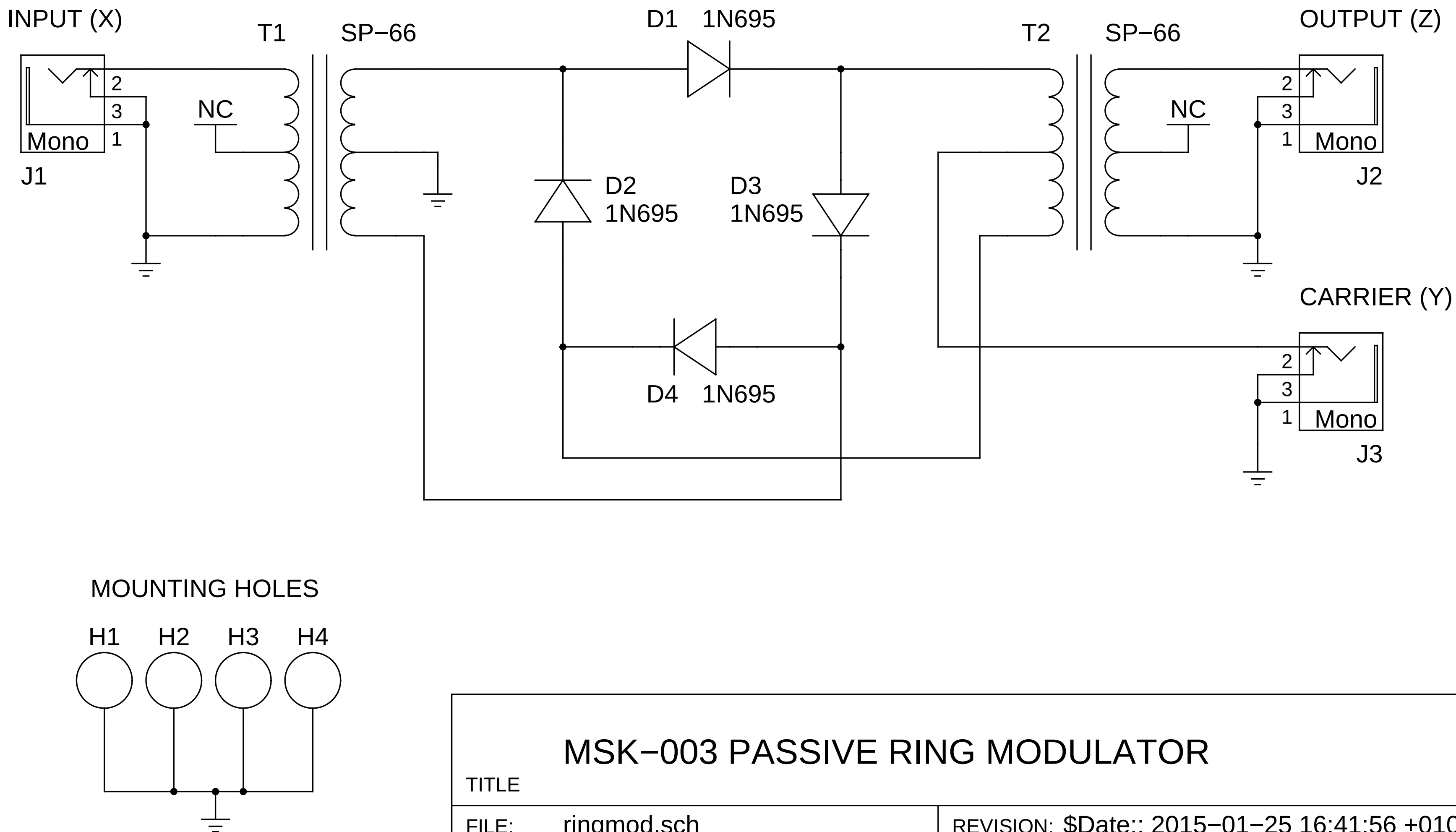


The ring will behave differently depending on the input levels, and signals straight out of Eurorack oscillators are probably a little hotter than optimal. Run either or both inputs through an attenuator first to get different effects.

A patch like this one is suggested in the Doepfer manual for their own (non-diode-based) ring modulator: use two oscillators driven by the same control voltage, but with a slew limiter on one of them. Then each time you play a new note, the timbre changes as the slew-limited oscillator tries to catch up.

If you use the same square wave as carrier for two ring modulators in series, the second will undo the modulation performed by the first and the output will just be a copy of the input (with some volume loss in the case of passive modulators). But if there is some other module in between, such as the DSP effect unit shown here, the other module will see the modulated, not the original, signal, and whatever changes are made by the DSP will be subjected to modulation in the final output. A spring reverb, phaser, wavefolder, or even just a low-pass filter could also produce interesting results.





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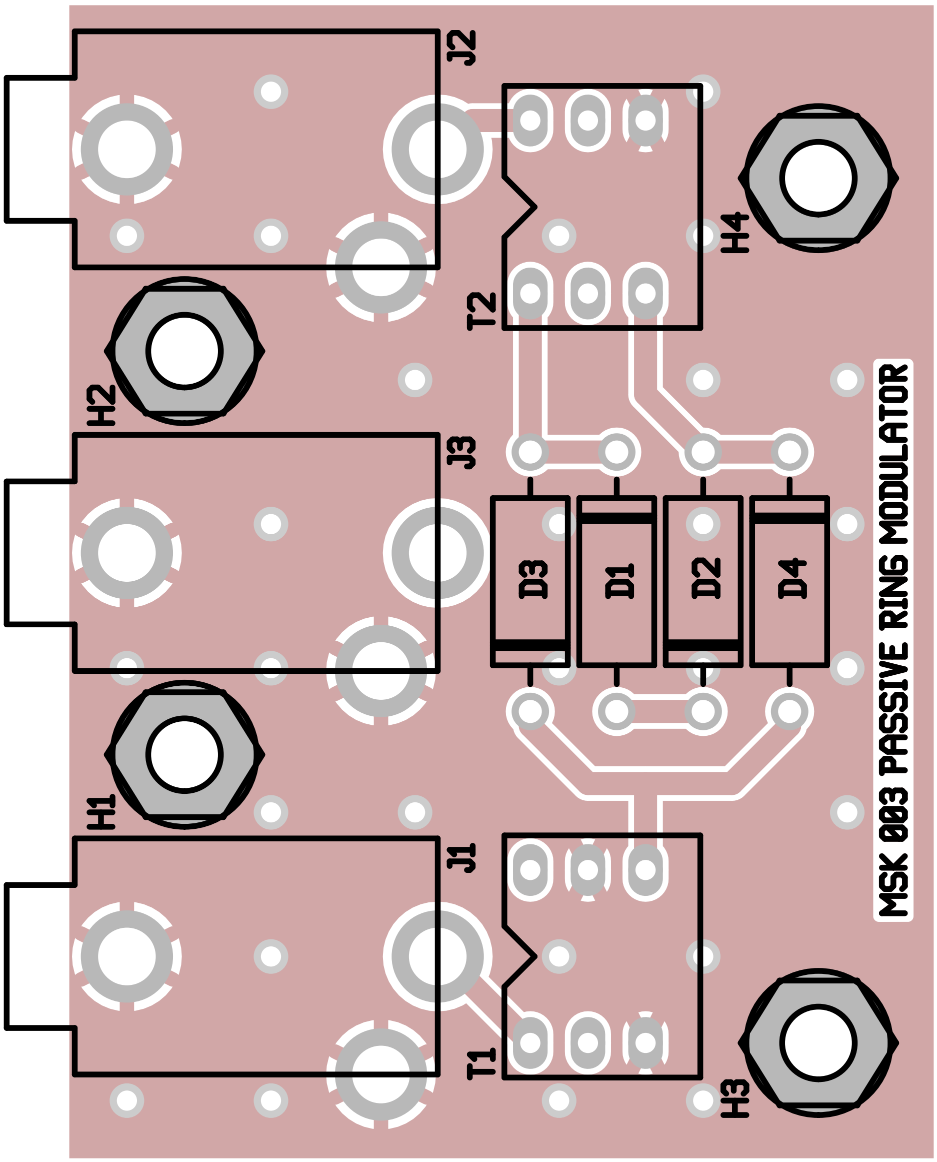

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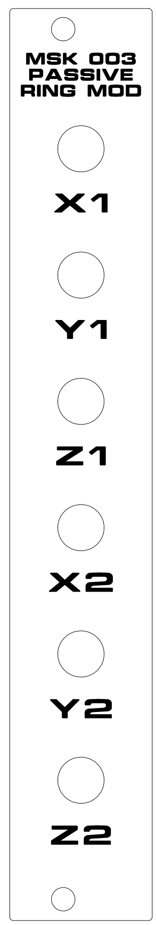
MSK 003
PASSIVE
RING MOD
X1
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