MSK 011 Transistor Mixer

North Coast Synthesis Ltd.
Matthew Skala

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Contents

General notes

This manual documents the MSK 011 Transistor Mixer, which is a utility mixer module for use with both audio and control voltages in a Eurorack modular synthesizer. It is a minimalist design using only six transistors and no integrated circuits.

Specifications

This module is designed to mount in 6HP of rack space in a standard 3U Eurorack case.

The module's maximum current requirement in ordinary use is 9mA on the +12V supply and 14mA on the −12V supply. Unusual loads on the outputs, including directly-connected headphones or speakers and so-called "passive" modules, may cause the MSK 011 to draw more than this amount of current. It does not require +5V power.

The input impedance is nominally 100kΩ for all inputs, varying a little with control knob positions. The output impedance is nominally 5kΩ. Separate AC and DC coupled outputs are provided. Shorting any input or output to any fixed voltage at or between the power rails should be harmless to the module; patching the MSK 011's output into the output of some other module on the same power system should be harmless to the MSK 011, though doing that is not recommended because it is possible the other module may be harmed.

Voltage gain for each channel can be adjusted between zero and a little more than unity. The mixer is designed to handle input and output signals over a range of at least ±8V; it is harmless to the module to drive the inputs all the way to the power rails, but such signals will clip.

The very simple Class A transistor amplifiers used in this module are subject to temperature-dependent DC offset. There is a trimmer provided on the circuit board for overall adjustment, and the DC level can be fine-tuned in many patches with the normalled offset controls on the front panel; however, in patches where it is important to avoid any DC offset at all, it may be preferable to use the AC-coupled output. Since it also may be difficult to adjust the gain controls to exactly unity, this mixer may not be the best choice for sensitive pitch-CV applications if one wants to keep the pitches exactly in tune; the North Coast Synthesis Ltd. MSK 008 Dual VC Octave Switch, with its precision adders based on op amp chips, may be a better choice for exact pitch control. The Transistor Mixer is intended, instead, for users who want to embrace the organic variability of classic discrete-transistor circuits.

This module (assuming a correct build using the recommended components) is protected against reverse power connection. It will not function with the power reversed, but will not suffer or cause any damage. Some other kinds of misconnection may possibly be dangerous to the module or the power supply.

Controls and connections

Here's a summary of the items on the front panel of the module.

inputs one for each of the four channels. Note the top one is normalled to a positive voltage (equivalent to roughly +6V) and the bottom to a negative voltage (about −6V).

gain controls one knob for each channel. These are non-inverting, logarithmic controls. For the top and bottom channels, if there is nothing plugged into the corresponding input jack, the knob controls the amount of DC offset. *You should set these knobs to zero, that is, fully counterclockwise, if you are not using them as inputs and don't want a DC offset.*

DC output the result of mixing the four inputs.

AC output same as the DC output, but with a simple filter to block DC. The cutoff frequency depends on the load you apply, but would typically be less than 1Hz, so this output is suitable even for control voltages if they are reasonably fast-moving.

Also note, on the circuit board behind the panel, the offset trimmer, labelled "R7 100k offset null." This will have been pre-set when the module was built, but it can be adjusted again later if necessary. Adjustment range for this trimmer is approximately ±2V.

Source package

A ZIP archive containing source code for this document and for the module itself, including things like machine-readable CAD files, is available from the Web site at https://northcoastsynthesis.com/. Be aware that actually building from source requires some manual steps; Makefiles for GNU Make are provided, but you may need to manually generate PDFs from the CAD files for inclusion in the document, make Gerbers from the PCB design, manually edit the .csv bill of materials files if you change the bill of materials, and so on.

Recommended software for use with the source code includes:

- GNU Make;
- LaTeX for document compilation;
- LaTeX.mk (Danjean and Legrand, not to be confused with other similarly-named LaTeX-automation tools);
- Circuit_macros (for in-document schematic diagrams);
- Kicad (electronic design automation);
- Qcad (2D drafting); and
- Perl (for the BOM-generating script).

The kicad-symbols/ subdirectory contains my customised schematic symbol and PCB footprint libraries for Kicad. Kicad doesn't consistently keep dependencies like symbols inside a project directory, so on my system, these files actually live in a central directory shared by many projects. As a result, upon unpacking the ZIP file you may need to do some reconfiguration of the library paths stored inside the project files, in order to allow the symbols and footprints to be found. Also, this directory will probably contain some extra bonus symbols and footprints not actually used by this project, because it's a copy of the directory shared with other projects.

PCBs and physical design

This module is built on a single PCB 4.20″×1.30″, or 106.68mm×33.02mm, which mounts perpendicular to the front panel. With about another 1mm of gap between the PCB and panel, the total depth requirement is 34mm.

Component substitutions

This circuit should work with almost any NPN transistors. We ship 2N5088 transistors in our kits and assembled modules, and these are high-quality silicon amplifier transistors with gain in the range of a few hundred; to be honest, they are higher specification than this circuit needs. Any transistors used should be able to handle the full power supply voltage (24V) between collector and emitter, and at least about 10mA of current. Low-gain transistors (less than about 30 or 40) may have some impact on the accuracy and available gain of the mixing, but if you are using such transistors, you probably intend for them to have an effect. Any other effects of transistor substitution are likely to be very subtle. It is not necessary to match transistors, though if two channel buffers have very different transistors in them, then those channels may end up sounding different from each other.

When substituting NPN transistors, connect the collector, base, and emitter to the pads marked “C,” “B,” and “E” on the board according to the pinout of the specific transistors you are using, even if that does not match the flat side of the TO-92 outline in the silkscreen (which refers to the 2N5088 pinout).

Fairchild/ON Semi, formerly the main manufacturer of 2N5088 transistors, announced their discontinuation while this product was in development. North Coast made a lifetime buy and we should be able to continue supplying kits and modules with 2N5088 transistors for the foreseeable future. As of this writing, Central Semiconductor still makes 2N5088 transistors. But most other small NPN amplifier transistors should also work well in this circuit and could be substituted; the transistor selection is not critical.

On substituting other components: we suggest 1% metal film fixed resistors throughout, because these days, they are cheap enough to use indiscriminately; however, it would probably still work fine with 5% resistors in most if not all locations. None of the resistors are particularly critical with respect to power handling and we supply different power ratings of resistors for different values according to what we can source easily. The output AC-coupling capacitor is designed as 4.7μF film for best performance, but it should be safe to substitute one a little smaller, or a non-polar electrolytic.

PNP transistor modification

This modification is only appropriate for advanced builders.

Because the circuit is so simple, it is possible to reverse the polarities of the components and build it with PNP instead of NPN transistors, without any changes to the board layout! This might be useful if one wants to use, for instance, vintage germanium transistors, which tend to be PNP type. However, it means disobeying the instructions on the board silkscreen, and attaching the power backwards; so it is not for the faint of heart.

To build using PNP transistors:

- Install PNP transistors on the board according to the silkscreen markings: collectors to “C,” bases to “B,” and emitters to “E.” Disregard the TO-92 outlines on the board, which may or may not match your transistors depending on their pinout.
- Install the diodes D1 and D2 *against* the silkscreen markings, with their cathodes in the circular pads pointing away from the silkscreen symbol’s stripe.
- Install the electrolytic capacitors C2 and C3 *against* the silkscreen markings, with their positive terminals in the circular pads marked “−.”
- Attach the power cable *upside down* (!), with its striped edge denoting the negative rail at the top of the connector on the module PCB, against the “−12V” marking on the silkscreen.

Modification for ±15V power

To change this circuit for ±15V power:

- Make sure all components (taking particular note of transistors and electrolytic capacitors) are rated for 30V.
- Change R17 to 2.4kΩ (was 2.7kΩ).
- Change R18 to 6.2kΩ (was 5.9kΩ).
- Substitute an appropriate power connection for the Eurorack power header.

The resistor changes were determined by simulation; I have not built a ±15V prototype for testing.

Use and contact information

This module design is released under the GNU GPL, version 3, a copy of which is in the source code package in the file named `COPYING`. One important consequence of the license is that if you distribute the design to others—for instance, as a built hardware device—then you are obligated to make the source code available to them at no additional charge, including any modifications you may have made to the original design. Source code for a hardware device includes without limitation such things as the machine-readable, human-editable CAD files for the circuit boards and panels. You also are not permitted to limit others’ freedoms to redistribute the design and make further modifications of their own.

I sell this and other modules, both as fully assembled products and do-it-yourself kits, 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. Even if you only use the free plans and cannot buy the commercial products I sell, any assistance you can offer to increasing the profile of North Coast would be much appreciated. For instance, you might post photos of your completed DIY build on your social media. The latest version of this document and the associated source files can be found at the North Coast Web site.

Email should be sent to
mskala@northcoastsynthesis.com.

Safety and other warnings

Ask an adult to help you.

North Coast Synthesis Ltd. does not offer warranties or technical support on anything we did not build and sell. That applies both to modules built by you or others from the kits we sell, and to fully-assembled modules that might be built by others using our plans. Especially note that because we publish detailed plans and we permit third parties to build and sell modules using our plans subject to the relevant license terms, it is reasonable to expect that there will be modules on the new and used markets closely resembling ours but not built and sold by us. We may be able to help in authenticating a module of unknown provenance; contact us if you have questions of this nature.

For new modules purchased through a reseller, warranty and technical support issues should be taken to the reseller *first*. Resellers buy modules from North Coast at a significant discount, allowing them to resell the modules at a profit, and part of the way they earn that is by taking responsibility for supporting their own customers.

We also sell our products to hobbyists who enjoy tinkering with and customizing electronic equipment. Modules like ours, even if originally built by us, may be quite likely to contain third-party "mods," added or deleted features, or otherwise differ from the standard specifications of our assembled modules when new. Be aware of this possibility when you buy a used module.

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.

Residue from traditional rosin-based solder flux can result in undesired leakage currents that may affect high-impedance circuits. This module does not use any extremely high impedances, but small leakage currents could still reduce its accuracy. If your soldering leaves a lot of such residue then it might be advisable to clean that off.

Voltage and current levels in some synthesizer circuits may be dangerous.

Do not attempt to make solder flow through the board and form fillets on both sides of every joint. Some soldering tutorials claim that that is desirable or even mandatory, it does look nicer, and it may happen naturally when the conditions are good and the leads happen to be small in relation to the holes. But with large wire leads that just fit in the holes, when the holes are connected to the ground plane (even through thermal reliefs), on some harder-to-wet lead finishes, with lead-free solder, and so on, you may only end up dumping excessive heat into the joint and damaging the components while you fuss over perfect fillets. A well-made solder joint that just covers the pad and makes good contact to the lead on one side of the board, is good enough.

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.

Bill of materials

This table is not a substitute for the text instructions.

Qty	Ref	Value/Part No.	
2	C4, C5	0.1μF	axial ceramic
1	C1	4.7μF	film, 0.2″ lead spacing
2	C2, C3	10μF	radial aluminum electrolytic, 0.1″ lead spacing
2	D1, D2	1N5818	or SB130; Schottky rectifier
2	H1, H2	M3x6	M3 machine screw, 6mm body length
2	H3, H4		nylon washer for M3 machine screw
1	J7		male Eurorack power header, 2×5 pins at 0.1″
6	J1–J6	MJ–3536	switched mono 3.5mm right angle jack, CUI
6	Q1–Q6	2N5088	NPN general purpose amplifier, TO-92 EBC
2	R19, R23	510Ω	
1	R17	2.7kΩ	
1	R22	4.7kΩ	
1	R18	5.9kΩ	
1	R21	12kΩ	
5	R8–R11, R20	22kΩ	
4	R12–R15	47kΩ	
4	R2–R5	100kΩ	horizontal conductive plastic panel pot, BI Technologies P260P series, audio taper
1	R7	100kΩ	horizontal single turn, Vishay T73YP or similar
2	R1, R6	100kΩ	
2	R16, R24	330kΩ	

Fixed resistors should be 1% metal film throughout. Capacitor values are not critical. Transistors may be substituted (see notes). RoHS-certified zinc-plated steel hardware is recommended, not stainless steel because of galvanic-corrosion incompatibility with aluminum parts.

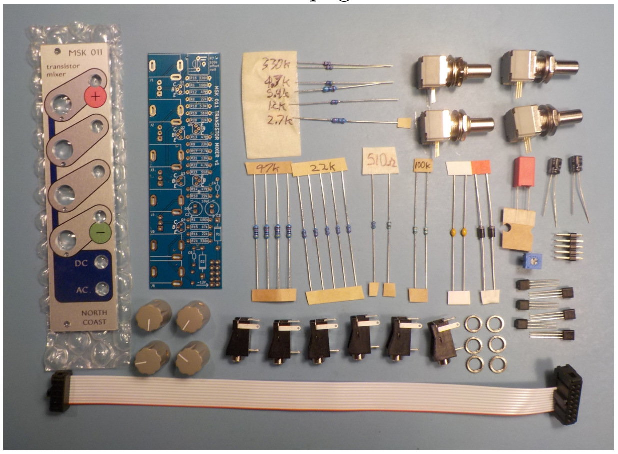
Also needed: solder and related supplies, PCB, panel, knobs, Eurorack power cable, etc.

Building the module

The circuit board has components on both sides, which makes the order of assembly important; installing the wrong components first may make it difficult to safely maneuver the soldering iron to install later components without damaging the already-installed components.

Preliminaries

Count out the right number of everything according to the bill of materials on page 8.



Some notes on knobs

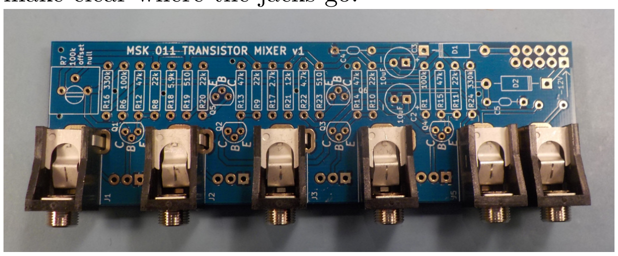
The first batch of knobs I ordered for North Coast products turned out to have serious quality problems, specifically with the setscrews that hold the knobs onto the potentiometer shafts. Some of the screws had marginal threads that would strip when the screw was tightened, and I ended up having to do a bunch of extra testing and ship extra knobs to some customers to replace any that might fail. Later batches have also had issues, although they're under better control now because the bad first batch served as a warning to step up the testing procedures. Starting with kits prepared in August 2019, I switched to blue knobs with 100% testing; in September 2020, I switched to a new manufacturer, and knobs that are a slightly darker shade of blue. Although all the knobs I ship in kits now have been tested and passed at least twice, and should be fine to use, I am also shipping spare setscrews in any kits with knobs from batches where a signficant number of knobs failed testing.

Here are some things to be aware of as a kit builder.

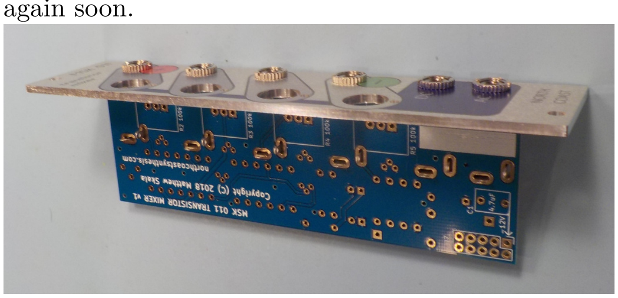
- Some photos in these instructions were taken with the older grey knobs, and some dealers may still have kits containing grey knobs in their stock, but newer kits will have blue knobs.
- Do not overtighten the setscrews when attaching the knobs! The screw should be tight enough to hold the knob onto the shaft, but there's no advantage to making it tighter than that, and overtightening may risk destroying the screw thread or damaging the drive slot.
- If, despite my efforts to make sure no bad screws get sent to customers, you still get a bad screw that cannot be tightened and no spare for it, then please contact me.
- If you want to source an exact replacement for the setscrew, it should be an M3×3mm flat-tip slotted setscrew, which is also sometimes called a "grub screw," made of RoHS-compliant brass (possibly by exemption). Stainless steel is fine too, and I may sometimes ship stainless steel screws instead of brass if I can find a reliable source for them; plain steel should not be used here for galvanic corrosion reasons. Hex-socket screws are fine if you have the driver for them, but I don't ship those because I'm not sure all DIY builders do have the right driver.
- Because it's a standard M3 thread, in a pinch it's possible to substitute a plain M3 machine screw such as are commonly used with Eurorack cases, although one of those would obviously look less nice.

Panel components

The components that go through the panel should be installed first because soldering them may be difficult later. First, place the six jack sockets J1 to J6 in their locations on the board. Note that the silkscreen for these may not be exactly as shown. I had one batch of boards in which the silkscreen lines perpendicular to the panel were missing. The text, and the short lines showing the backs of the jack bodies, should still make clear where the jacks go.

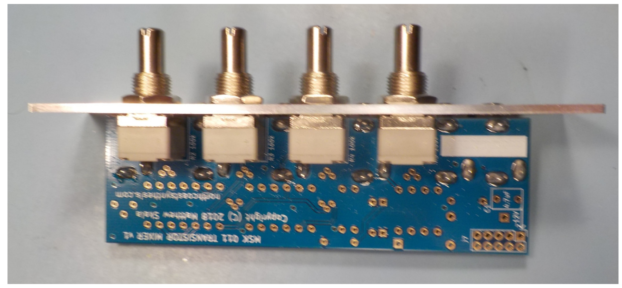


Attach the panel to the jack sockets using the knurled nuts that came with the jacks. It should be snug, but not tight; you will be removing the panel again soon.



Solder the jack sockets in place.

Remove the panel, place the four 100kΩ panel potentiometers R2–R5 in their locations on the opposite side of the board, then reinstall the panel. As with the jack sockets, it is possible that the silkscreen markings for these on the board may not be exactly as shown in the photo here. Use just a nut (not the other mounting hardware) to hold the potentiometers in place, and again tighten them only moderately, because this is a temporary assembly. Depending on the board tolerances, the legs of the potentiometers may be bent somewhat when installed this way. Be careful when soldering them not to damage the nearby plastic of the jack sockets. Because cleaning these joints may be difficult, it is advisable to use no-clean and not water-washable solder flux. Similarly, because of the limited access it is probably better not to attempt to clip the leads after soldering.



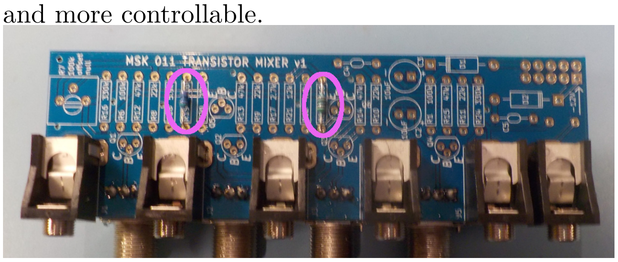
At this stage you have the option to leave the panel attached through the rest of the assembly, which will protect the pots from getting bent out of position, or remove it, which will allow for more convenient access to solder other components. For the photos in these instructions, I have removed the panel for a clearer view of the components, but it may really be a better idea to leave it in place. Without the panel, the pots are supported delicately on their legs and may easily be bent or damaged by careless handling.

Note it is not recommended to try to do the jack sockets and potentiometers in a single step without removing the panel in between, because of the difficulty of making the large solder joints on the jacks while the potentiometers are in place without damaging them. This assembly routine, although convoluted, really seems to be the safest and easiest way to do it. Having parts on both sides of a single board is part of the price paid for keeping the module to only 6HP width.

Fixed resistors

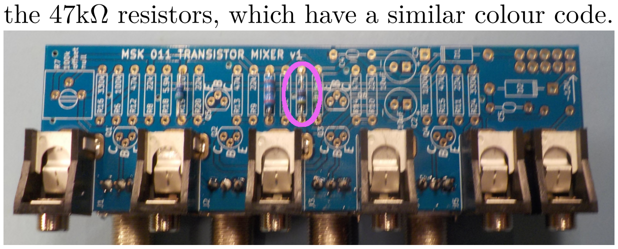
Resistors are never polarized. I like to install mine in a consistent direction for cosmetic reasons, but this is electrically unnecessary. In this module, metal film 1% resistors are recommended for all fixed-value resistors. These will usually have blue bodies and four colour bands designating the value, plus a fifth band for the tolerance, brown in the case of 1%. These are the resistors normally shipped in the North Coast kits, but we may occasionally ship better-tolerance resistors (such as 0.5%) if we are able to source them at a good price. Accordingly, I mention only the four value band colours for this type of resistor; if you are using resistors with other codes, you are responsible for knowing them. Note that colour codes on metal film 1% resistors are often ambiguous (reading from one end or the other end may give two different values, both plausible) and some of the colours are hard to distinguish anyway. If in doubt, always measure with an ohmmeter before soldering.

Install the two 510Ω (green-brown-black-black) resistors R19 and R23. These are emitter degeneration resistors for the transistors Q5 and Q6; they make the gain of those amplifying transistors smaller and more controllable.

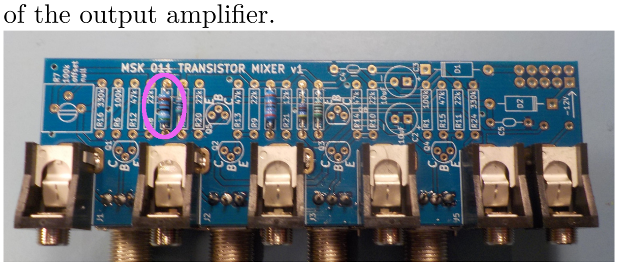


Install the 2.7kΩ (red-violet-black-brown) resistor R17. This resistor scales the output of the passive mixing network to the appropriate range for the output amplifier.

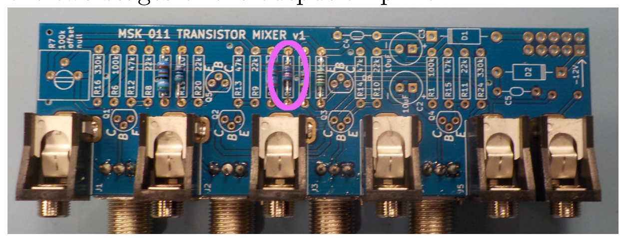
Install the 4.7kΩ (yellow-violet-black-brown) resistor R22. This resistor sets the gain for the second stage of the output amplifier. Do not confuse it with the 47kΩ resistors, which have a similar colour code.



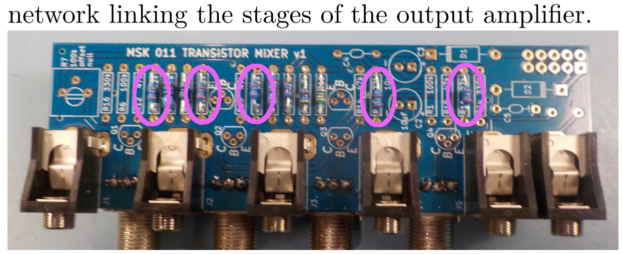
Install the 5.9kΩ (green-white-black-brown) resistor R18. This resistor sets the gain for the first stage of the output amplifier.



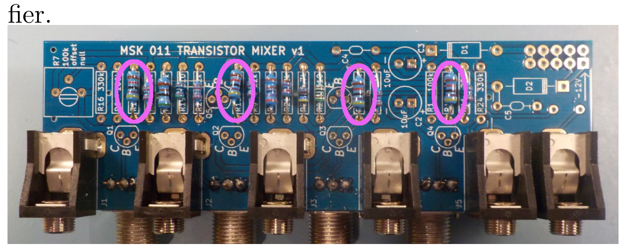
Install the 12kΩ (brown-red-black-red) resistor R21. This resistor is part of the network that links the two stages of the output amplifier.



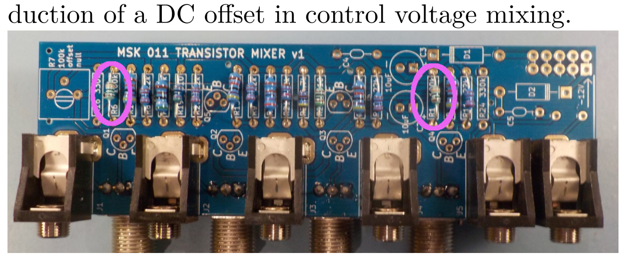
Install the four 22kΩ (red-red-black-red) resistors R8 to R11 and R20. Most of these provide voltage pull-down for the input buffers; R22 is part of the network linking the stages of the output amplifier.



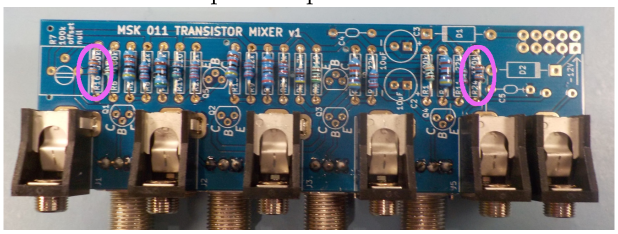
Install the four 47kΩ (yellow-violet-black-red) resistors R12 to R15. These resistors form the mixing network between the input buffers and output amplifier.



Install the two 100kΩ (brown-black-black-orange) resistors R1 and R6. These provide normalling voltages for the top and bottom knobs, to allow introduction of a DC offset in control voltage mixing.



Install the two 330kΩ (orange-orange-black-orange) resistors R16 and R24. R16 controls the scale of the offset null trimmer, and R24 eliminates DC offset at the AC-coupled output.

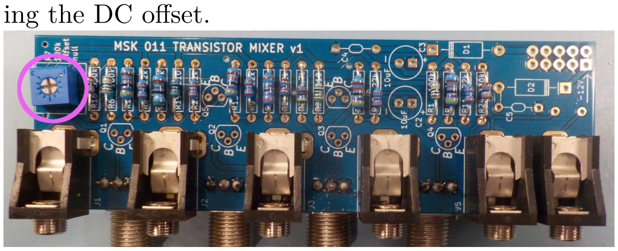


Trimmer potentiometer

Trimmers are not exactly polarized, but the three legs of a trimmer serve different functions and need to be connected to the right holes. The physical arrangement of the legs and corresponding holes should make it impossible to install the trimmer wrong way round.

Also note that the silkscreened footprint for the trimmer on this board provides a generous amount of space, for maximum flexibility in parts substitution; the trimmers usually shipped in North Coast kits will not fill the space.

Install the 100kΩ trimmer R7. This is for adjusting the DC offset.



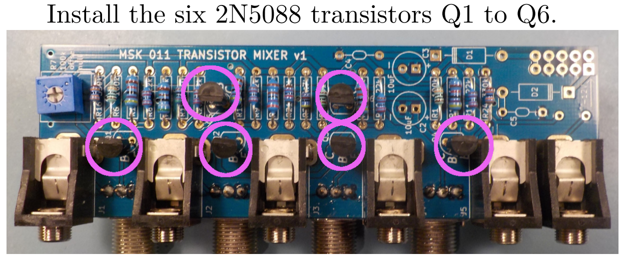
Transistors

The six NPN transistors in this project are polarized and must be installed in the correct orientation to work; that orientation is shown by the silkscreen symbols. Install each component so that its flat side points in the same direction as the flat side shown on the silkscreen. The three legs of the component must be carefully bent into the same triangular pattern (left and right forward, middle backward) as the holes on the board, and then the component pressed into place. There should be a gap of about three millimetres between the board and the component body; do not attempt to seat the component flush on the board because of the risk of breaking off the legs where they enter the body.

To aid in modifications with different components, the three holes for each transistor are also labelled with the letters "E," "B," and "C," for "emitter," "base," and "collector." If you are using some other transistors, connect them to match those markings according to the pinout of the parts you are using, even if that puts the flat side of the package other than where it is shown on the silkscreen.

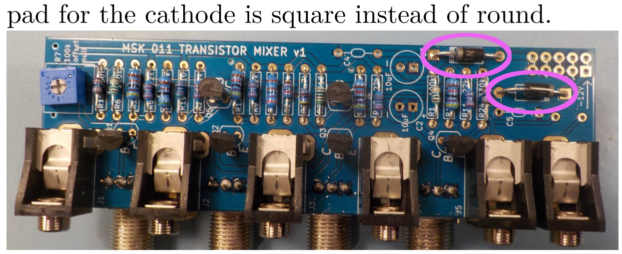
The solder pads for these components are smaller and closer together than for any other through-hole components in the project, and the components themselves tend to be relatively heat-sensitive. Solder them carefully, avoiding creating any solder bridges between adjacent pads. Do not use excessive time and heat trying to get the solder to flow through the board and fillet on both sides, especially not on pads connected to the ground plane; two-sided fillets may happen naturally, but it is enough for solder to completely cover the pad on one side.

Install the six 2N5088 transistors Q1 to Q6.



Diodes

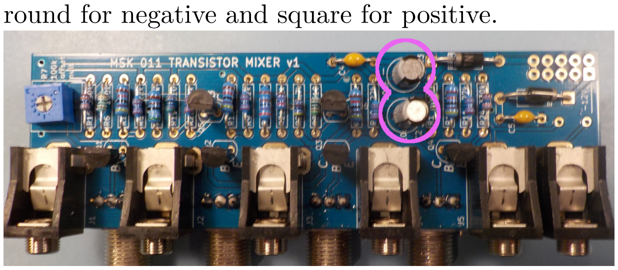
Install the two Schottky diodes D1 and D2. These protect the module against reverse connection of the power supply. They are polarized and must be installed in the correct direction; otherwise they will prevent the module from operating. One end of each diode will be marked, usually with a stripe of grey paint around the black plastic body of the diode. That end is called the *cathode*. The diode outline on the PCB silkscreen is marked with a similar stripe showing the direction of the cathode, and the solder pad for the cathode is square instead of round.



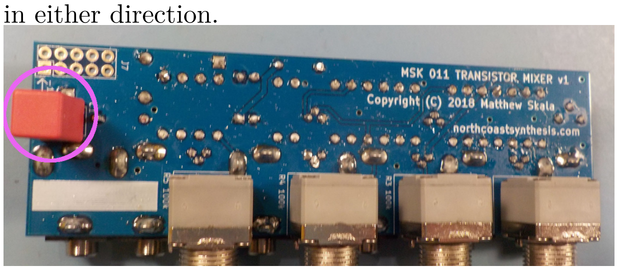
Capacitors

Install the two 0.1μF ceramic capacitors C4 and C5. These filter out high-frequency interference on the power supply lines. These capacitors are not polarized and may be installed in either orientation.

Install the two 10μF electrolytic capacitors C2 and C3. These filter lower-frequency interference on the power lines. They are polarized components, and may explode if connected backwards. As such, there are multiple clues to help you install them in the right direction. The negative leg of each capacitor will be marked in some way, usually with a printed stripe and minus signs on the plastic wrapping of the capacitor body. The negative leg of the capacitor will usually also be shorter, though that is less reliable than the body markings. On the PCB, the positive and negative pads are marked with positive and negative signs in the silkscreen, and the solder pads themselves are round for negative and square for positive.

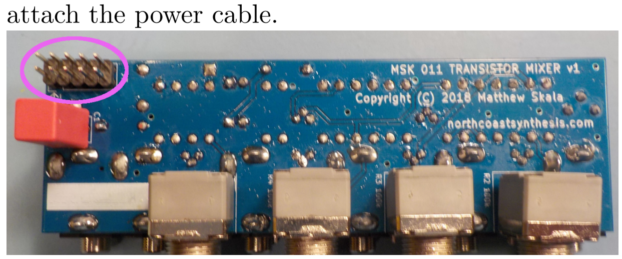


Install the 4.7μF film capacitor C1. This capacitor provides AC coupling for the corresponding output. It goes on the back of the board, and needs to be installed at this point, late in the build, so as not to conflict with the solder connections of other nearby components. It is not polarized and may be installed in either direction.



Power header

Install the 10-pin dual-row Eurorack power header J7. This header goes on the back of the board, with C1 and the panel pots, opposite from most of the other components. It is not polarized in the horizontal plane. However, if it has shorter legs on one side, then those are the ones that should go through the PCB (leaving the longer legs sticking up to mate with the connector on the power cable), and if it has tin plating on one end of the pins and gold on the other, then the tin side should be the one soldered through the board. Secure the header carefully to the board, possibly with tape, before soldering it. It is easy to accidentally solder it at an angle, which is a difficult error to fix and may cause trouble when you later attach the power cable.



Note that Eurorack power connections are polarized even if the connectors are not. The cables are usually grey ribbon type with a red stripe along one side indicating pin 1, which carries -12V power. For most modules including the MSK 011, the red stripe should be at the *bottom* when the module is mounted vertically in a case. On the MSK 011, the correct location of the -12V supply is also marked with the text "-12V" and arrows on both sides of the PCB silkscreen. This module is also protected (by the Schottky diodes you just installed) from damage in case of a reversed power connection; if you connect the power backwards and nothing else is wrong, then the module will not power up but will be fine once you connect the power correctly. However, many other modules are not so protected, and it is dangerous to get into the habit of depending on protection diodes. Destroying a module by connecting power backwards is almost a rite of passage for Eurorack users.

Final assembly

If you have removed the panel, reattach it; if you have left it in place, undo the nuts on the potentiometers and add the rest of the hardware. The sequence of hardware for the potentiometers is first (nearest the panel) the conical spring washer, high side in the middle and low side around the outside; then the toothed lock-washer; then the nut. In the case of the jack sockets, the knurled nuts provided for these will have screwdriver slots on one side, and those should face the outside with the smoother side facing the panel.

Do not overtighten any of this hardware, and be careful, if you are using wrenches or pliers, to avoid scratching the panel. Wrapping the tool jaws with tape may help.

Attach the knobs to the potentiometers. Twist each shaft to its limits in each direction to ascertain how the slot in the shaft corresponds to where you want the knob pointer, then slide the knob onto the shaft in the correct orientation and tighten the setscrew with a small flat screwdriver.

There is a rectangular white area on the back of the board reserved for adding a serial number, signature, quality control marking, or similar. Use a fine-tipped permanent marker to write whatever you want there.

Your module is complete.

Adjustment and testing

The MSK 011 is designed to work with very little adjustment. As a result of its minimalist transistor-based design, there is unavoidably some temperature-sensitive offset in the DC-coupled output. A trimmer is provided to help null this out, but because of the temperature sensitivity the offset will probably never remain at zero in practical use. For audio applications it is preferable to use the AC-coupled output.

This adjustment procedure requires the finished module, a smallish cross-tip screwdriver, a suitable power supply, and a multimeter.

Short-circuit test

With no power applied to the module, check for short circuits between the three power connections on the Eurorack power connector. The two pins at the bottom, marked with an arrow on the circuit board, are for -12V. The two at the other end are for +12V; and the remaining six pins in the middle are all ground pins. Check between each pairing of these three voltages, in both directions (six tests in all). Ideally, you should use a multimeter's "diode test" range for this; if yours has no such range, use a low resistance-measuring setting. It should read infinite in the reverse direction (positive lead to −12V and negative lead to each of the other two, as well as positive lead to ground and negative to +12V) and greater than 1V or 1kΩ in the forward direction (reverse those three tests). If any of these six measurements is less than 1kΩ or 1V, then something is wrong with the build, most likely a blob of solder shorting between two connections, and you should troubleshoot that before applying power.

Optional: Although we test all cables before we sell them, bad cables have been known to exist, so it might be worth plugging the Eurorack power cable into the module and repeating these continuity tests across the cable's corresponding contacts (using bits of narrow-guage wire to get into the contacts on the cable if necessary, or probing the pins of the power connector on the back side of the circuit board) to make sure there are no shorts in the cable crimping. Doing this test *with the cable connected to the module* makes it easier to avoid mistakes, because the module itself will short together all wires that carry equal potential, making it easier to be sure of testing the relevant adjacent-wire pairs in the cable.

Plug the module into a Eurorack power supply and make sure neither it nor the power supply emits smoke, overheats, makes any unusual noises, or smells bad. If any of those things happen, turn off the power immediately, and troubleshoot the problem before proceeding.

Optional: Plug the module into a Eurorack power supply *backwards*, see that nothing bad happens, and congratulate yourself on having assembled the reverse-connection protective circuit properly. Reconnect it right way round before proceeding to the next step.

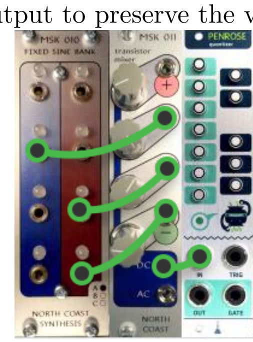
Output offset adjustment

Turn all knobs fully counterclockwise. Apply power to the module with nothing plugged into the input, and measure the DC voltage of the DC-coupled output. Adjust R7 at the top of the board, labelled "offset null," to bring the output as close to 0V as is reasonably possible. It is unlikely that you will be able to get it to stay at exactly zero.

Patch ideas

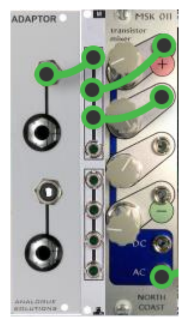
The basic operation of the MSK 011 is very simple: it mixes signals. Here, an oscillator and noise source are combined before being fed into a filter. Using the AC-coupled output is appropriate for audio signals where no DC offset is desirable. Remember to turn down the top and bottom knobs, which function as offset generators, if they are not in use.

This patch combines three slow sine waves from an MSK 010 to generate a melody. The top knob is left unpatched and can be turned up to generate a positive offset, shifting these bipolar signals into the 0...5V range needed by the quantizer. Note use of the DC-coupled output to preserve the voltage levels.



Applying a DC offset (top and bottom knobs), then removing it with the AC-coupled output, allows the module to clip signals in a controlled way on one side, for even-harmonic distortion.

Each channel has maximum gain somewhat over unity, but to boost a signal further, you can feed it into two or more channels and turn them all up. Shown here with a passive cable-adapter module; you might use a patch like this to boost an external signal a little bit.



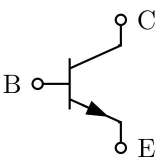
For more gain, use feedback from the DC-coupled output to a channel and then take the result from the AC-coupled output. This arrangement will amplify any DC offset too, so it may require some careful adjustment of the top or bottom knobs to cancel out that effect. Voltage gains of up to 10 seem to be reasonably stable; in principle there is no limit. Feedback through the AC-coupled output would cancel most of the offset, but may have phase problems. The mixer will probably not oscillate under any purely self-patched configuration, though (like any mixer) it could be combined with other modules, such as filters, into more complicated feedback patches.

Circuit explanation

The MSK 011 is an attempt at minimalist design; the simplest transistor-based mixer circuit that will still be usable. It is designed with modern components, which makes some issues easier to address, but the basic operating principles go all the way back to the earliest transistor (and, to some extent, vacuum tube) amplifying circuits.

Transistor rules

Consider a simple NPN bipolar transistor.



The behaviour of all the transistors in the MSK 011 can be understood by two simple rules. These are only approximations, and they are specific to NPN transistors operating in the mode used here.

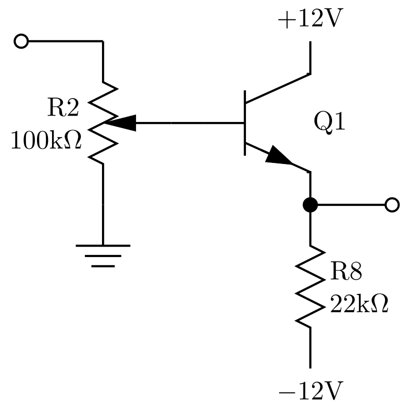
Current rule: The current flowing into the collector (C) is approximately equal to the current flowing out of the emitter (E), and there is approximately no current through the base (B).

Voltage rule: The base is approximately 0.7V more positive than the emitter, and the collector is whatever voltage it needs to be to obey the current rule, provided that is above the emitter voltage.

These rules cut in all directions. A transistor will, to the extent it can, change the voltages and currents at all of its terminals in order to obey the rules—changing the voltage at the emitter to be 0.7V less than the base when the base is driven to a specific voltage by external circuity, but also changing the voltage at the base to 0.7V above the emitter when the emitter is driven to a specific voltage, and so on. If the transistor cannot obey the rules, then they are not sufficient to understand the circuit in question and we need to apply other, more detailed, theory. But in the MSK 011 during normal operation, these simple rules are a good description of what is going on.

Input buffers

The MSK 011 contains four input buffers. Here is the schematic for one of them; the others are identical.



The signal enters from the right and is attenuated by the potentiometer R2. Depending on the position of the knob, somewhere from 0 to 100% of the input voltage is applied to the base of Q1. Then, by the voltage rule, the transistor will drive its emitter to 0.7V less than the voltage applied to the base. That will draw some amount of current through the resistor R8, and the same amount of current is drawn from the power supply at the transistor collector.

The load at the input jack looks like a fairly constant 100kΩ resistance; the transistor only places negligible load on whatever is driving the input. Meanwhile, we can push or pull a relatively large amount of current through the output and the transistor will adjust its current draw from the positive power supply to keep the output at the right voltage, always 0.7V less than the attenuated input. If something else tries to pull the output up, then up to the limit of the roughly 500μA of current that is flowing through R8, the transistor will just provide a smaller share of that current and allow the external circuit to provide the rest, keeping the voltage across the resistor unchanged. Similarly, if the external circuit tries to pull the output down, the transistor (up to its limits) will just draw more current from the positive supply to satisfy the external circuit while keeping its emitter 0.7V below its base.

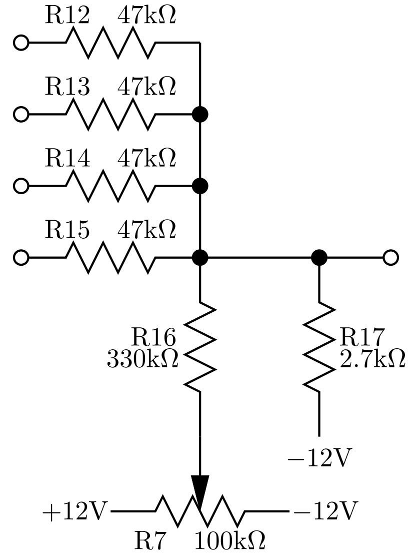
Therefore, what happens at the output of this circuit in terms of current draw is not seen at the input. The input is said to be "buffered" against fluctuations in the output. Such a buffer is useful in this mixer module because it helps prevent crosstalk between the input channels.

This kind of transistor circuit is called an *emitter follower*, because the voltage at the emitter follows or copies (except for the 0.7V offset) the voltage applied to the base. It is also called a *common collector amplifier*; the collector of the transistor is connected to the "common" connection of the positive power supply. Although this circuit has no voltage gain (it adds an offset, but does not multiply voltage changes in the input by anything other than 1), it serves as a current amplifier because the current available at the output is potentially much more than that consumed at the input.

One detail not shown on the above diagram, but visible in the full schematic on page 22, is the input normalling: channels 1 and 4 have the switching contacts on their jack sockets connected to the power supplies through 100kΩ resistors, so that if there is no signal plugged into these channels, you can turn up their knobs to create a DC offset (positive for channel 1, negative for channel 4). Because of the 100kΩ resistors in series with the 100kΩ resistance of the attenuator pot, the maximum offset in either direction is about 6V.

Mixing network

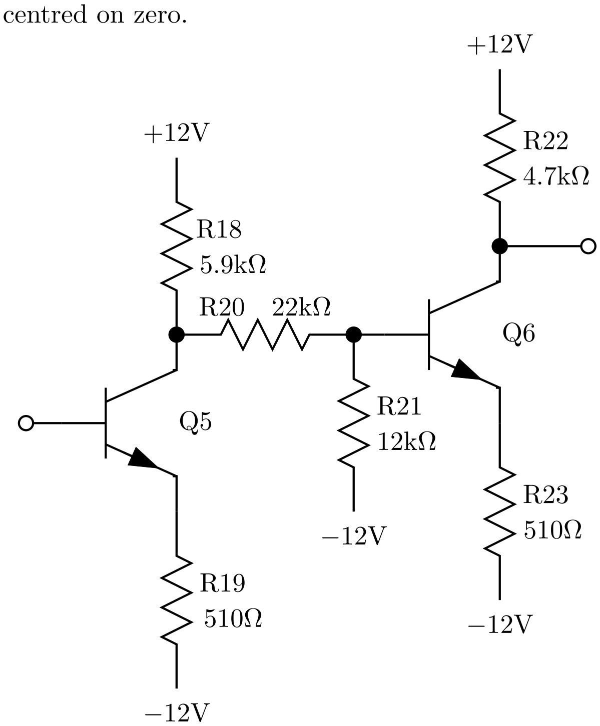
After buffering, the four input signals go through a passive mixing network which combines them in equal proportion, attenuating them and shifting them into a range of voltages near the negative power supply, in order to hit the desired input range for the output amplifier. This network is adjustable with a trimmer pot on the circuit board, to compensate for variations in the offsets of the transistors throughout the circuit, which are only (under the voltage rule above) *approximately* 0.7V each.



Note the low-valued resistor R17, just 2.7kΩ to the negative supply. The other resistances are much larger, making this network function as a fairly strong fixed attenuator; the large signal range at the input translates into a small range at the input of the next stage.

Output amplifier

The signal from the mixing network needs to be amplified back up to modular level, and shifted to be centred on zero.



This is a two-stage *common emitter* amplifier; the emitter of each transistor is connected (through the low-value resistors R19 and R23) to the common −12V power supply.

As the input signal runs over its small range near the lower power supply voltage, the transistor Q5 (under the voltage rule) forces its emitter to follow that voltage, approximately 0.7V down. This voltage across the 510Ω resistor R19 induces a proportional current. Then, under the current rule, the transistor draws the same amount of current through the 5.9kΩ resistor R18, which causes the voltage across that resistor to also vary in proportion. The collector voltage of Q5 floats to take up the slack voltage, in accordance with the transistor voltage rule. But because R18 is *a bigger resistor*, the same current variation causes a larger voltage variation across R18. The circuit exhibits voltage gain: a small voltage change on the input results in a larger voltage change on the output.

As a first approximation we can say that the voltage gain of the first stage (Q5) is equal to R18 divided by R19; a change of 1V on the transistor base and therefore on R19 results in 1/R19 current change which results in R18/R19 voltage change on R19. Really, the gain is a little less than that because of the current consumed by the resistive coupling network between Q5 and Q6. A more accurate estimate comes from measuring the ratio between R19 and the parallel combination of R18 with the R20+R21 network, which gives a voltage gain of −9.86. The voltage gain is *negative*. Lower voltages on the input give higher voltages on the output (at the collector of Q5), because lower input voltages mean less current through R19, less current through R18, and therefore less voltage drop across R18, bringing the collector of Q5 and low end of R18 closer to the positive supply.

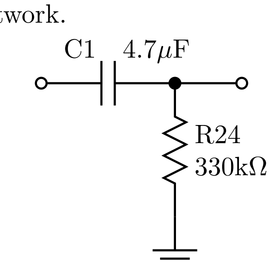
The inverted signal at the collector of Q5 goes through the resistor network (R20 and R21) to again bring it into the negative-voltage range needed for input to one of these common-emitter stages, and then Q6, R22, and R23 amplify and invert it again. The Q6 amplifier stage has a little bit less voltage gain because of the smaller resistor R22, but otherwise is identical in operation to the Q5 stage. And the result is used directly as the module's DC-coupled output.

The main reason for using *two* amplifier stages here is so that the module's overall response will be non-inverting. Another reason is that, despite the loss in the coupling network between the two stages, doing it this way allows each single amplifier to work at a lower gain, which makes it easier to control their gains precisely and reduces risks from things like feedback. The 2N5088 transistors recommended here can run comfortably at much higher gain per stage, but using them that way would make the response more dependent on variation among individual transistors, temperature, and so on.

AC coupling network

The output from Q6 is used directly as the DC-coupled output of the module. Having a DC-coupled output is more or less necessary in a Eurorack mixer because people want to use them for DC control voltages. However, it is an unavoidable fact of using such a minimal circuit design that there is some dependence on transistor behaviour, and in particular, on temperature. That offset between base and emitter that I called "approximately 0.7V" actually depends a lot on temperature, and a little on the individual transistors. One consequence is that the exact ranges of signal voltages will shift with temperature; zero voltage on all inputs to the mixer may not give zero volts at the DC-coupled output. The offset trimmer can be adjusted to eliminate the offset at some typical temperature, but as the temperature changes, it will fall out of trim again.

So for use with audio signals, the MSK 011 also provides an AC-coupled output, using a simple RC high-pass network.

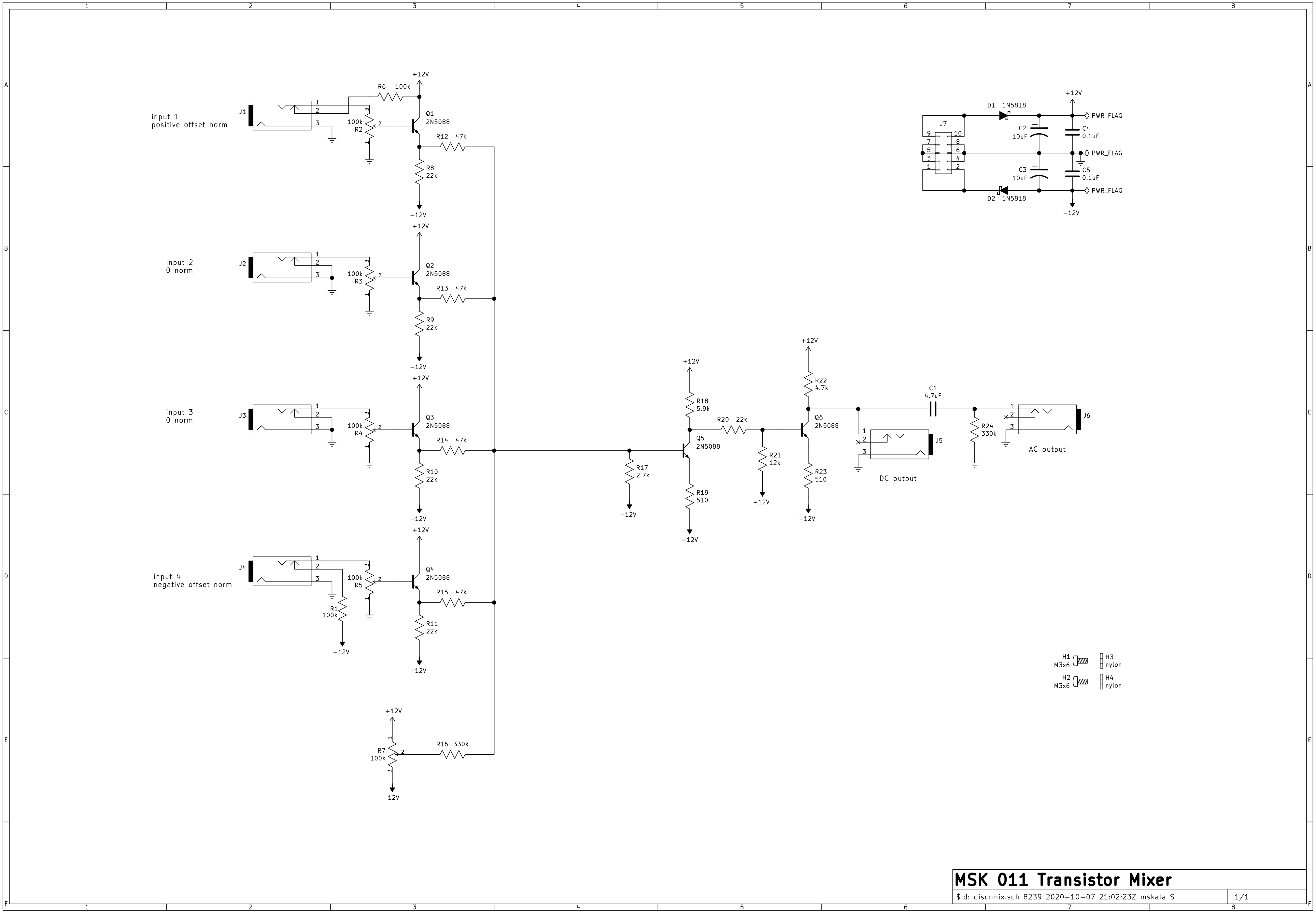


Applying the formula for RC cutoff frequency with a 4.7μF capacitor and 330kΩ resistor suggests that this will roll off signals below about 0.10Hz. Really, the input impedance of whatever it's plugged into, appearing in parallel with R24, will have the effect of reducing the resistance and increasing the corner frequency; but even driving a low-impedance "passive" module it should pass all reasonable audio frequencies. The real point of R24 is not so much to create a controlled roll-off frequency as to drain away any static charges that might from time to time appear on the output pin; and the point of the network as a whole is to block DC.

Mechanical drawings

On the following pages you will find:

- the schematic diagram for the module;
- a mock-up of what the completed module looks like from the front panel;
- the top-side silk screen art showing component placement;
- the bottom-side silk screen art showing component placement (*note this drawing is mirrored, and shows what you actually see looking at the board, not the X-ray view used in other Kicad output*);
- a mechanical drawing of the front panel showing the locations and sizes of the holes in it; and
- an exploded isometric drawing showing how the boards and hardware fit together.



input 1
positive offset norm
input 2
0 norm
input 3
0 norm
input 4
negative offset norm
J1
J2
J3
J4
J5
J6
J7
R6 100k
Q1 2N5088
Q2 2N5088
Q3 2N5088
Q4 2N5088
Q5 2N5088
Q6 2N5088
100k R2
100k R3
100k R4
100k R5
R1 100k
R7 100k
R12 47k
R13 47k
R14 47k
R15 47k
R16 330k
R8 22k
R9 22k
R10 22k
R11 22k
R17 2.7k
R18 5.9k
R19 510
R20 22k
R21 12k
R22 4.7k
R23 510
R24 330k
C1 4.7uF
DC output
AC output
D1 1N5818
D2 1N5818
C2 10uF
C3 10uF
C4 0.1uF
C5 0.1uF
PWR_FLAG
+12V
−12V
H1 M3x6
H2 M3x6
H3 nylon
H4 nylon
MSK 011 Transistor Mixer
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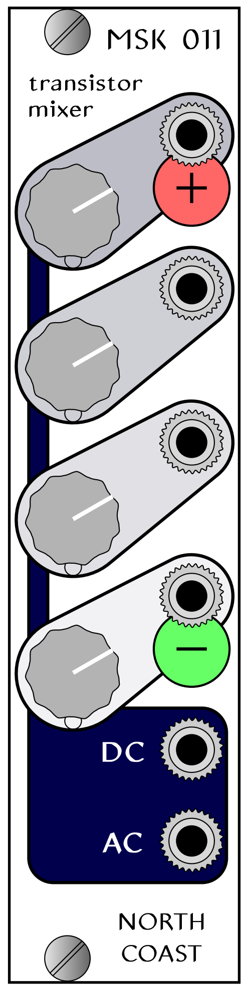
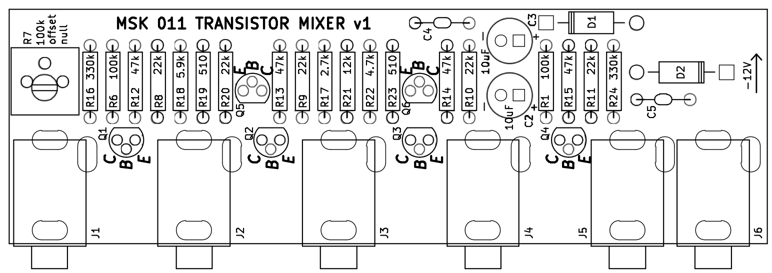
1/1


MSK 011
transistor
mixer
+
−
DC
AC
NORTH
COAST



MSK 011 Transistor Mixer

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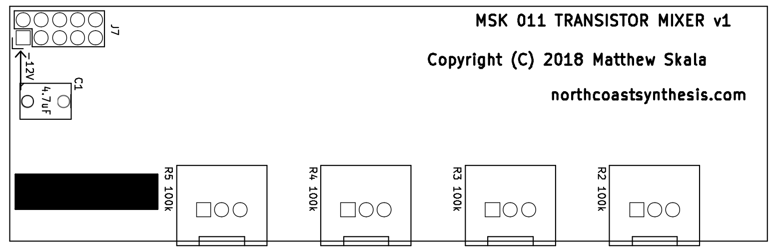

MSK 011 Transistor Mixer

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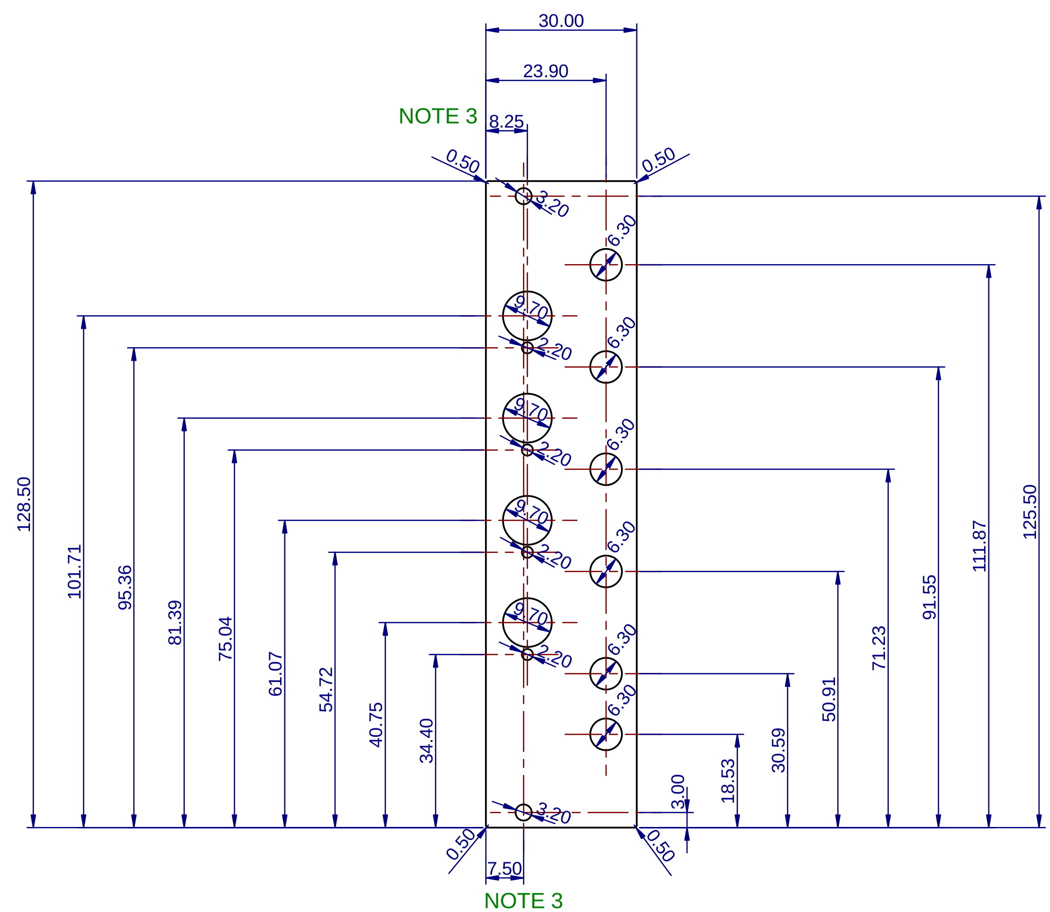

NOTES

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

2: Material is aluminum, 2.00mm thick. Overall dimensions are 128.50mm by 30.00mm, per Doepfer spec for a 6HP Eurorack synthesizer module.

3: Do not confuse similar horizontal positions. The 3.20mm panel-to-rails mounting holes are centred 7.50mm from the left edge. The 9.70mm and 2.20mm holes for the potentiometers are centred 8.25mm from the left edge.

MSK 011 Transistor Mixer panel mechanical	
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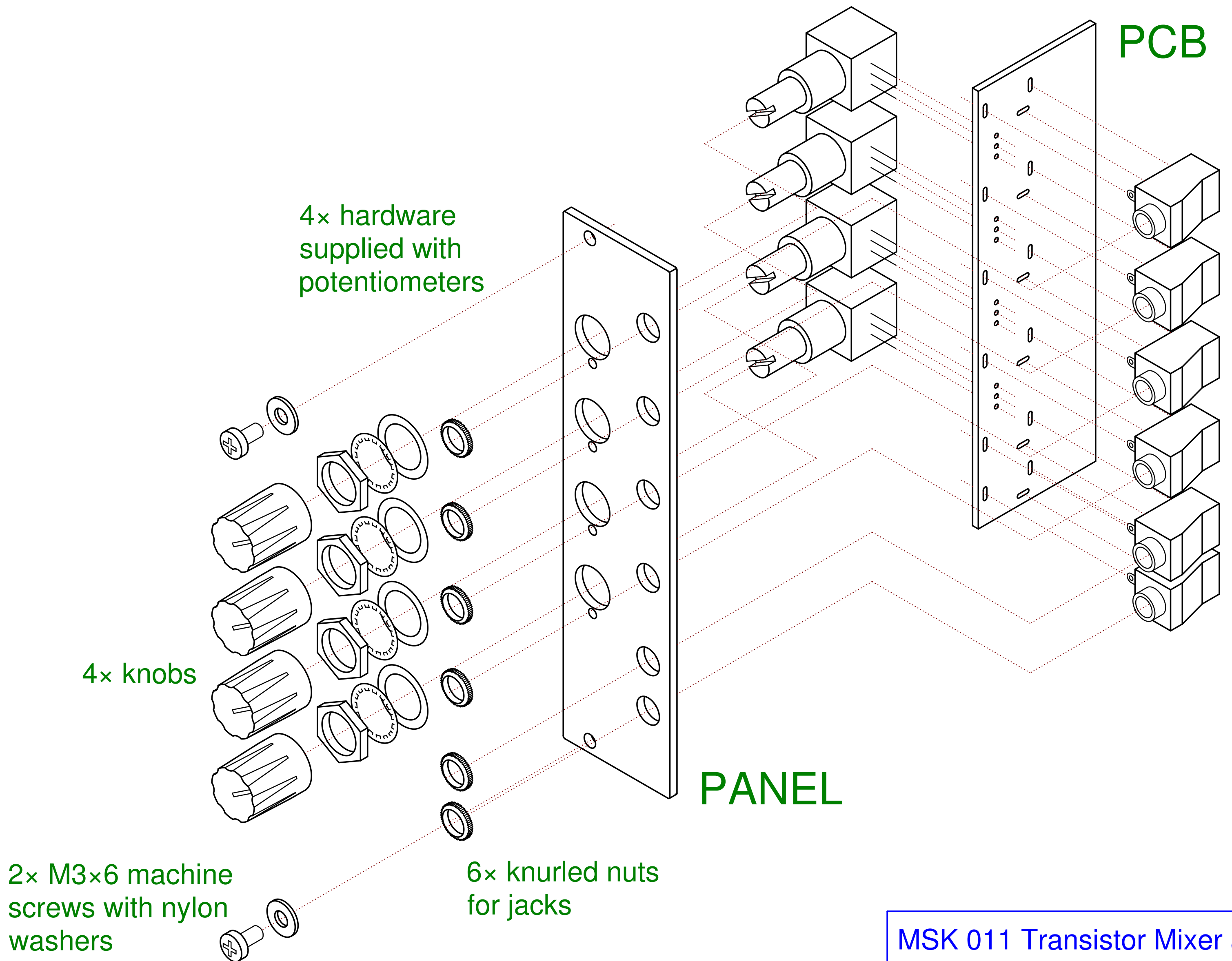

MSK 011 Transistor Mixer assembly diagram

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1/1