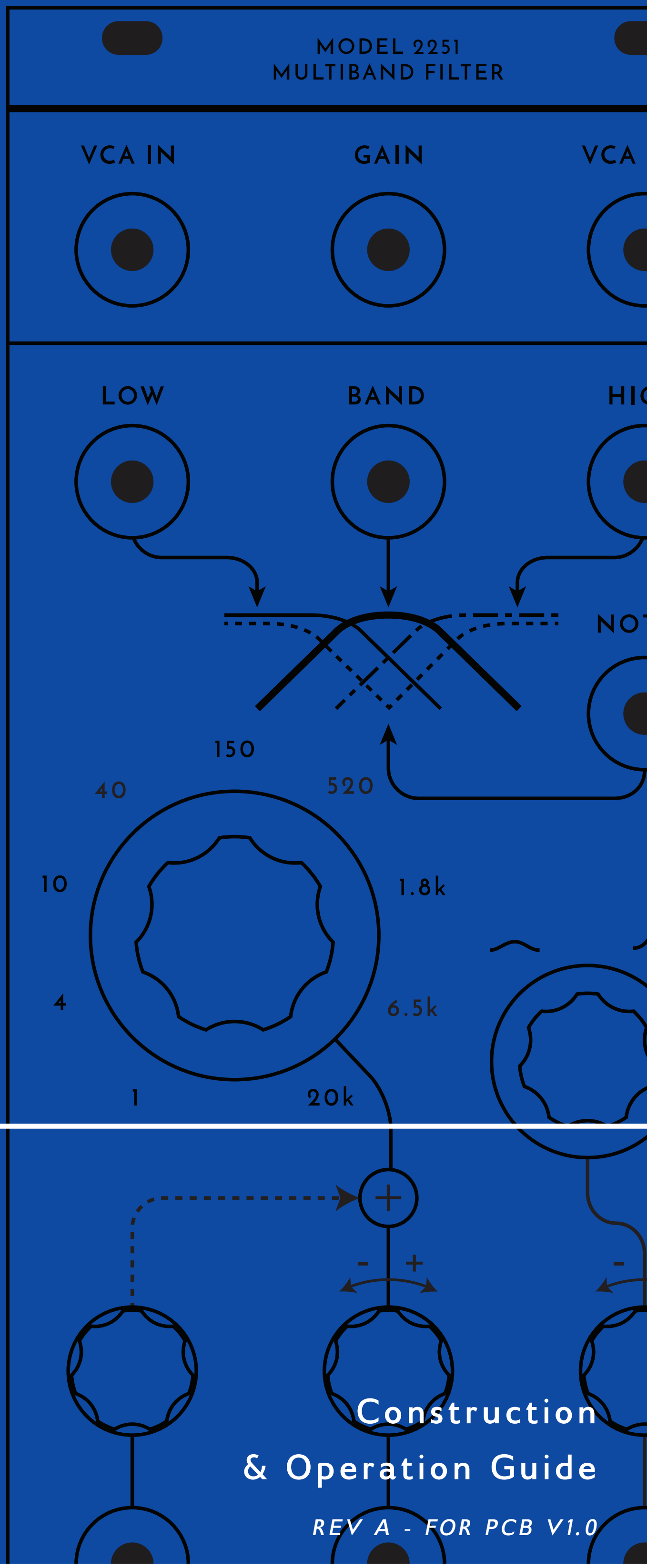
MODEL 2251

Multiband Filter

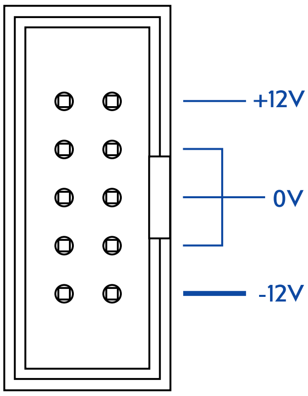


Construction & Operation Guide

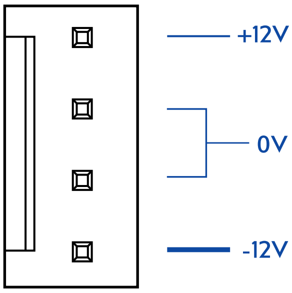
REV A - FOR PCB V1.0

SLIGHTLY NASTY ELECTRONICS ADELAIDE, AUSTRALIA

SPECIFICATIONS



IDC power connector pinout.



MTA-156 power connector pinout.

PHYSICAL

FORM FACTOR:	Loudest Warning / 4U
WIDTH:	3NMW / 75.5mm
HEIGHT:	175mm
DEPTH:	~40mm from panel front inc. components
PCB:	70 x 75mm, Two-Layer Double Sided
CONNECTORS:	4mm Banana

ELECTRICAL

POWER:	**+12V, 0V, -12V**
CONSUMPTION:	~25mA +12V Rail, ~25mA -12V Rail
CONNECTOR:	IDC 10-pin Shrouded Header, Eurorack Standard **or** MTA-156 4-Pin Header
I/O IMPEDANCES:	100K input, 1K output (nominal)

INPUT RANGES (nominal)

SIGNALS:	+/- 5V
FREQ:	+/- 5V
RES:	+/- 5V
GAIN:	0 - 5V

OUTPUT RANGES (nominal)

OUTPUT (ALL):	+/- 5V

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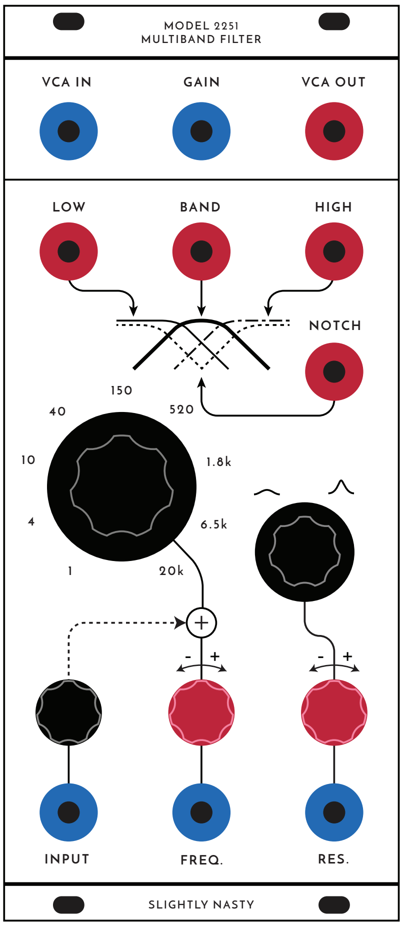
INTRODUCTION



The **Slightly Nasty Model 2251 Multiband Filter** is a versatile multimode 12dB/Oct state-variable filter that provides four simultaneous filter outputs: lowpass, highpass, bandpass, and notch. Both cutoff frequency and resonance are CV-controllable, with attenuverters provided for both. A dedicated audio FM knob allows add extra texture to be added without tying up an external mixer. In addition, one of the unused LM13700 OTA stages is used to implement a bonus utility VCA that operates independently of the filter.

The 2251 was designed to provide very controlled and consistent resonance across the operating range, so that very dynamic CV control of the resonance within a patch would always result in controlled and predictable signal amplitudes without excessive distortion or clipping. The resulting character of the filter is quite smooth, while still providing a satisfyingly big analogue filter sound suitable for basses, leads, and general sound design.

Despite this self-limiting resonance, the filter still self-oscillates and can be "pinged" by setting the resonance on the threshold of oscillation and hitting the audio input with a transient signal.

The Audio FM knob allows for some additional dirt and texture to be easily added by modulating the cutoff frequency with the input signal, which results in a sound somewhere between soft distortion and harmonic FM. The extra VCA is ideal as a final envelope/output VCA, meaning that a single oscillator and 2251 filter can provide a complete signal path for basic subtractive synth sounds.

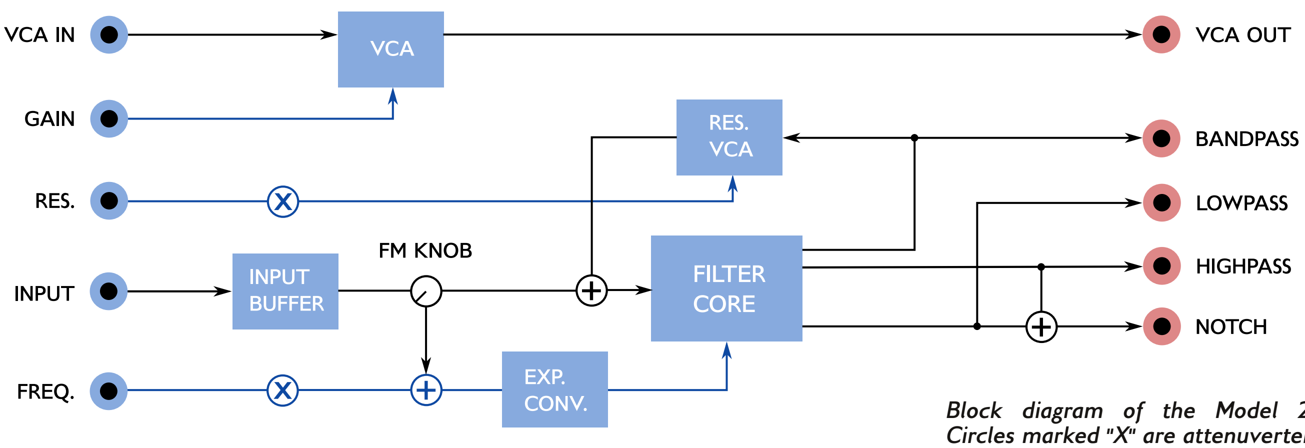
The Model 2251 uses the Loudest Warning 4U format for the front panel, and follows Eurorack electrical and power standards. All front panel components are PCB mounted for easy wiring-free construction. The front panel is available in two finishes - satin anodised and gloss white powdercoat, both on 2.5mm aluminium with robust UV-printed graphics.

CIRCUIT OVERVIEW

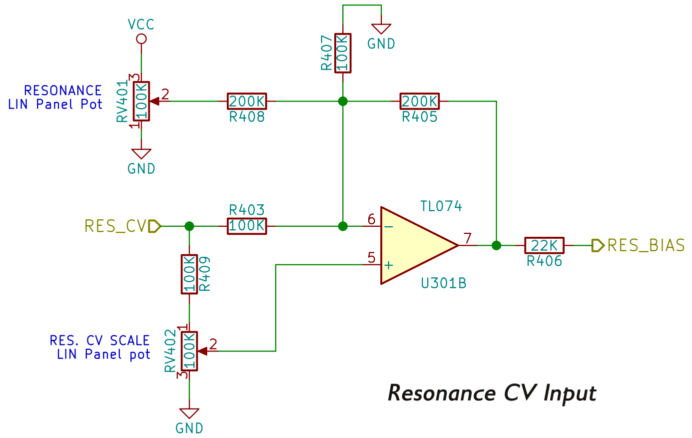
For full schematics, please download the separate schematics PDF. Excerpts shown in this manual may be outdated and are provided for reference only.

The 2251 is really a fairly basic module in terms of architecture, with a filter core surrounded by some simple buffering and CV processing elements, along with a bonus utility VCA. The functional blocks are divided as follows in the schematics:

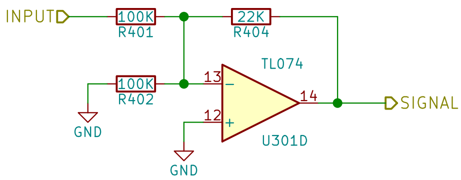
1. **CV/Signal buffers** - These buffer the inputs for the resonance CV and the audio signal input. The resonance CV buffer also serves as an attenuverter for additional control functionality.
2. **Exponential Converter** - This converts the linear input CV into an exponential current that controls the cutoff frequency of the filter core. This also includes the buffer/attenuverter for the frequency CV input and associated front panel controls. This allows for the possibility 1V/Oct tracking (with careful setting of the attenuverter!) and can also be temperature compensated if desired.
3. **Filter Core** - The filter core is a 2-pole state-variable design that provides simultaneous lowpass, highpass, and bandpass outputs, with a VCA-modulated feedback path creating a voltage controlled, self-limiting resonance. An additional mixer stage creates a notch output by mixing the low- and high-pass signals.
4. **Extra VCA** - As half of one of the LM13700 OTA ICs is unused by the rest of the circuit, a bonus VCA can be provided to extend the functionality of the module.



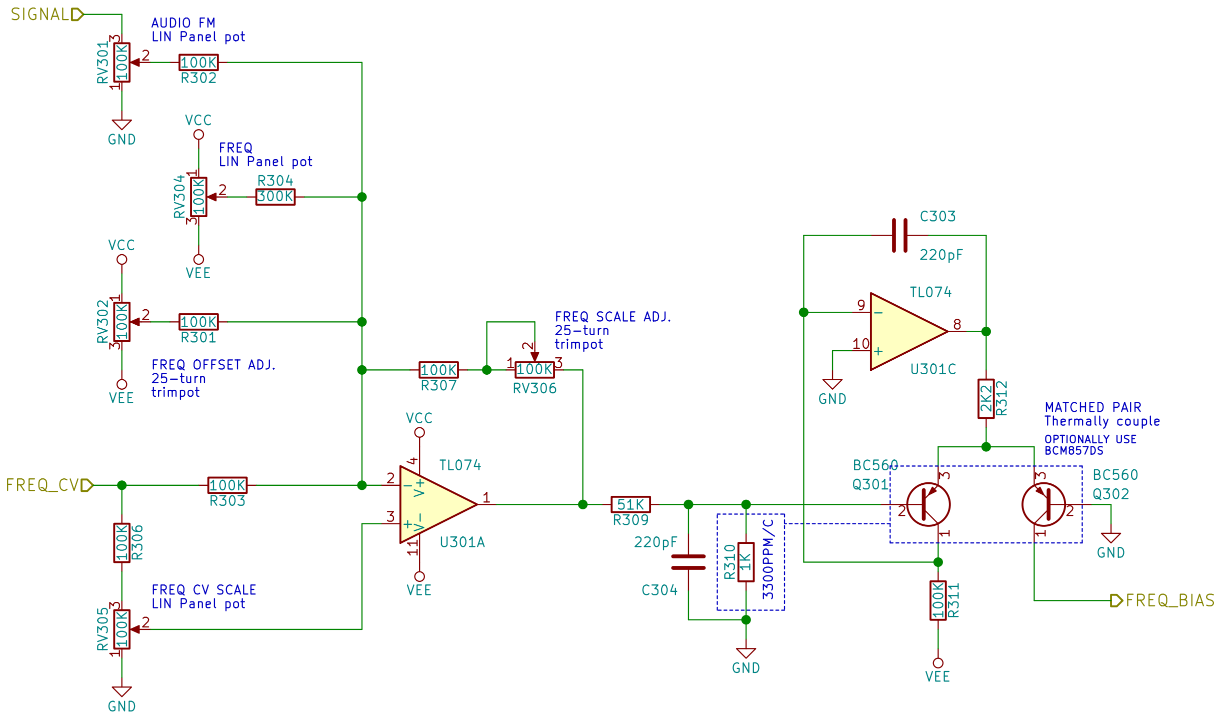
Block diagram of the Model 2251. Circles marked "X" are attenuverters.



Resonance CV Input



Signal Input



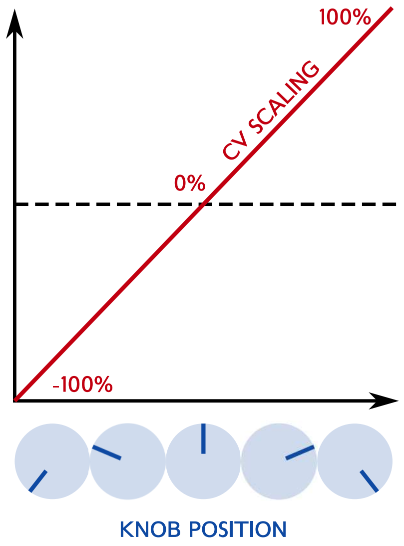
NOTE:
If accurate pitch tracking is not required,
a standard 1K resistor may be used for
R310, and unmatched transistors fitted
in Q301 / Q302. In this arrangement
thermal coupling is not required.

Exponential Converter

SIGNAL / RES CV INPUTS

The 2251's audio input is buffered by an inverting amplifier stage built around U301D, that also drops the amplitude of the signal from the full 10v peak-to-peak level of modular signals to just under a quarter of that. This gives a more reasonable amount of headroom for the later filter processing.

The resonance CV gœs into an attenuverter stage built around U301B, which allows potentiometer RV402 to control the balance of the signal between the inverting and non-inverting inputs of the opamp. Additionally, the front panel resonance pot feeds into the summing node at the inverting input, where it is mixed with the CV.



Demonstration of the attenuverters' operation. As the knob is turned clockwise the CV is scaled from -100% (or fully inverted) to 0% at top dead centre, then up to 100%.

EXPONENTIAL CONVERTER

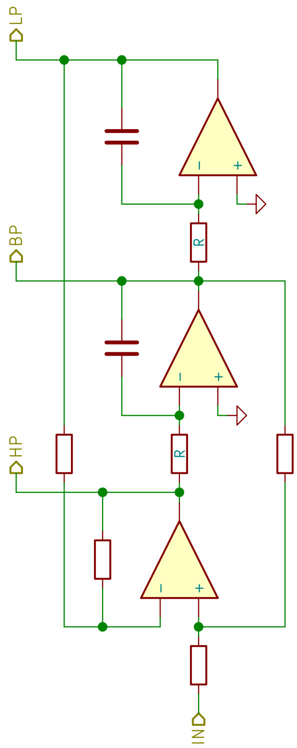
As pitch is perceived logarithmically, the linear frequency CV needs to be converted to an exponential response (doubling for each octave) in order to control the filter core in a musical way. The circuit used is the classic constant-current matched-transistor circuit used in most synthesiser circuits that require exponential conversion (particularly oscillators and filters). In this circuit, a constant current (provided by **U301C**) is fed through one leg of a differential transistor pair formed by **Q301** and **Q302**, causing the inherently exponential relationship between the transistors' base-emitter voltage (at low voltages) and their emitter current to appear in the second leg.

You may ask why two transistors are required if a single transistor already has this linear-exponential property, and the answer is temperature stability - the voltage - current relationship of a single transistor is VERY temperature sensitive, and the use of a differential pair in this arrangement allows this temperature dependency to be cancelled out by using two transistors with matching temperature response. Precise operation requires either hand-matching a pair of BC560 transistors, or using a matched pair in the form of a surface-mount BCM857DS chip, though many users will probably not need this.

This arrangement dœs not account for some additional temperature dependencies in the circuit, which is why for extra stability **R310** should be a 3300ppm/C TEMPCO resistor. Together with **R309** this forms a voltage divider that cancels these remaining dependencies. **C304** provides some lowpass filtering of the CV input for stability.

The other opamp (**U301A**) is configured similarly to the resonance CV input, with a combination of attenuverter and inverting summing amplifier to mix the various frequency controls, inputs, and trimmers.

FILTER CORE



General topology of a state-variable filter, with a summing stage followed by two integrators, and feedback paths returning from each opamp stage. In the case of a voltage-controlled filter like the 2251, the OTA stages take the place of the two resistors marked "R" in order to control cutoff frequency.

The rightmost resistor (or lower-most if viewed the right way up!) is responsible for the resonance amount, and in the 2251 is replaced with the resonance OTA.

The filter core in the 2251 is a state-variable topology, which uses a pair of integrators (**U201B** and **U201C**) with feedback into a summing amplifier (U201A) to create an analogue computer that solves a second-order differential equation. The mathematics involved here are far too complex to get into in a manual like this, but thankfully there is a way to get a more intuitive view of what the circuit is doing.

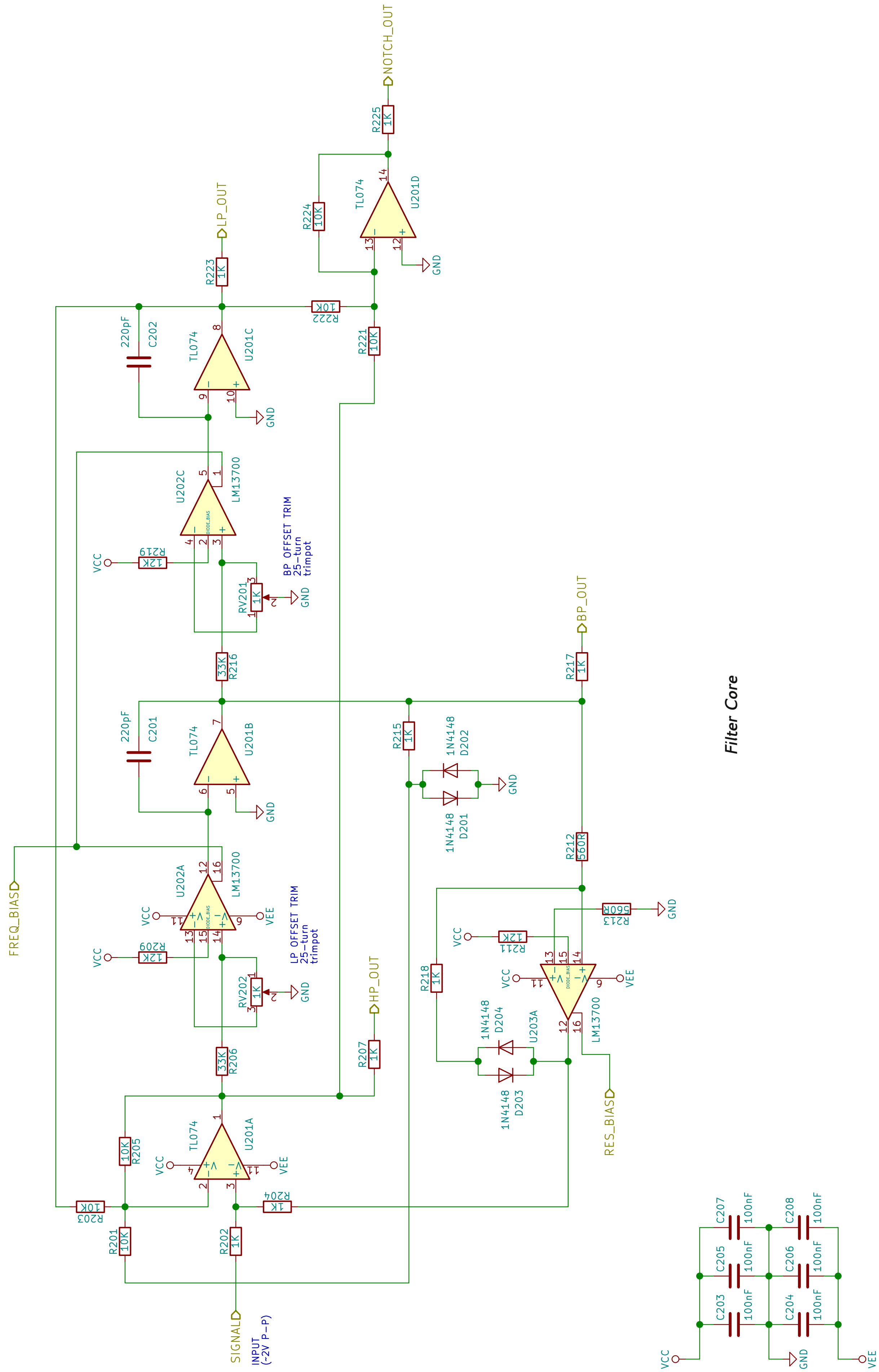
The basic state-variable circuit (ignoring the function of the OTA stages **U202A**, **U202C**, and **U203A**) is essentially an analogue computer that is performing a simulation of the classic model of a **damped mass-spring system**, like those used in high school physics textbooks to illustrate the properties of basic dynamic systems. Essentially we can see the circuit as a damped-mass spring system that is being excited by the audio signal, where the resonance is determined by the "bounciness" of the mass-spring system, and the filtering action by the damping (or resistance to movement). This gives us a resonant lowpass at the main output of the network, with the other modes obtained by tapping the circuit at various midway points.

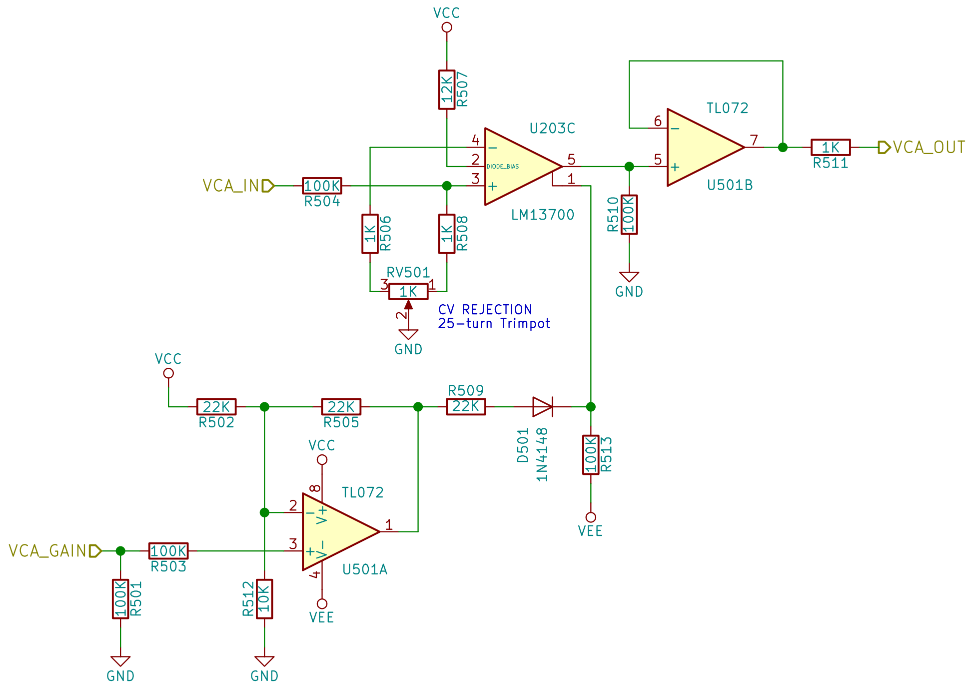
In order to change the parameters of our dynamic model, the two LM13700 OTA stages of **U202A** and **U202C** are configured as current-controlled amplifiers to change the scaling of terms in our differential equation. These take in the current provided by the exponential converter. Resonance level is controlled by **U203A**, which provides similar scaling of the feedback from the first integrator.

You may have noticed already that there are actually **two** feedback paths coming from the first integrator, and this is where we get into the self-limiting behaviour of the 2251. The diodes **D203** and **D204** along with **R218** provide the main limiting element of the circuit, soft-clipping the feedback path to prevent excessive build-up of resonance. However this works a little too well - with just this feedback path the filter will not reach self oscillation, and this is where the second feedback path comes in.

This second path is independent of the scaling of **U203A** and provides a static amount of low-level clipped feedback to the other input of the summing amp, just enough to allow the circuit to reach and maintain oscillation at higher resonance. Together with the main feedback path this gives us the resonance behaviour we're after - controlled but still versatile.

The main state-variable circuit dœs not in itself provide a notch response output - this mode is created by simply mixing the lowpass and highpass outputs in **U201D**, the combination of the two signals' frequency response and phase offsets creates a signal with a deep notch at the cutoff frequency.


Filter Core
NOTCH_OUT
LP_OUT
BP_OUT
HP_OUT
FREQ_BIAS
RES_BIAS
SIGNAL
INPUT
(~2V P-P)
BP OFFSET TRIM
25-turn
trimpot
LP OFFSET TRIM
25-turn
trimpot
TL074
LM13700
U201A
U201B
U201C
U201D
U202A
U202C
U203A
1N4148
VCC
VEE
GND



EXTRA VCA

Because the LM13700 ICs contain two OTA units each, and only three are used in the filter itself, there's still one left over which can be put to good use. In this case the extra OTA is used to implement a general purpose VCA with basic functionality.

The VCA design is very simple - the signal gœs into the OTA, is scaled according to the current provided by U501A, and is buffered by U501B before going to the output jack. The additional circuitry around U501A is needed to scale and offset the gain CV to the levels that will work with the LM13700 (which references its control input somewhat inconveniently from the negative rail).

R509 is what converts the output voltage of the U501A opamp into a current, with D501 used to add a slight "dead zone" to the bottom of the CV response. This prevents signal bleed when the VCA is supposed to be "off", R513 also helps pull the voltage at the OTA's control input down closer to the negative rail, to make up for the TL072 opamp's inability to output voltages too close to the supply voltages.

R510 is necessary because the LM13700, as an OTA, has a current-mode output. This appears as a voltage across R510 which we can then treat as a normal voltage signal.

RESISTORS		
10R	2	R101, R102
560R	2	R212, R213
1K	12	R202, R204, R207, R215, R217, R218, R223, R225, **R310***, R506, R508, R511 ***3300ppm/C Tempco if temperature stability required**
2K2	1	R312
10K	7	R201, R203, R205, R221, R222, R224, R512
12K	4	R209, R211, R219, R507
22K	5	R404, R406, R502, R505, R509
33K	2	R206, R216
51K	2	R303, R309
100K	15	R301, R302, R306, R307, R311, R401, R402, R403, R407, R409, R501, R503, R504, R510, R513
200K	2	R405, R408
300K	1	R304

CAPACITORS		
220pF	4	C201, C202, C303, C304
100nF	10	C203, C204, C205, C206, C207, C208, C301, C302, C501, C502
100uF	2	C101, C102

POTENTIOMETERS		
1K **25-turn**	3	RV201, RV202, RV501
10K **25-turn**	1	RV306
100K **25-turn**	1	RV302
100K **linear**	5	RV301, RV304, RV305, RV401, RV402

SEMICONDUCTORS		
1N4148	5	D201, D202, D203, D204, D501
BC560	2	Q301, Q302 **Match if temperature stability required**

INTEGRATED CIRCUITS		
LM13700	2	U202, U203
TL072	1	U501
TL074	2	U201, U301

CONNECTORS		
Banana Jacks	10	
IDC 10-pin Shrouded Header	1	P101 ***(Option 1)***
MTA-156 4-pin Header	1	P101 ***(Option 2)***
16-pin IC socket	2	
14-pin IC socket	2	
8-pin IC socket	1	
10-pin 2.54mm pin header	2	***Use standard breakaway strip***
10-pin 2.54mm female pin header	2	

HARDWARE		
M3 x 20mm Screw	4	
M3 Washer	16	
10mm Threaded Metal Hex Spacer	4	
M3 Nut	4	

CHOOSING COMPONENTS

Like all Slightly Nasty modules, the 2251 is designed to use common "jellybean" components wherever possible, so getting hold of parts is relatively straightforward. All resistors should be metal film 1% type, and capacitors are normal electrolytic and film types.

While the vast majority of uses for the 2251 will not require accurate or stable pitch tracking, those who want to make the exponential converter as accurate as possible will need to either select a matched pair of BC560 PNP transistors or use a BCM857DS matched transistor IC. Matching transistors is covered in depth in the **Slightly Nasty Model 1011 construction manual**, which is recommended reading for those wanting to go this route.

In the same vein, the optional use of a 3300ppm/C tempco resistor is only needed if this extra tracking stability and precision is desired. Otherwise a standard 1K resistor will suffice.

The module is designed to use either side or top-adjustment 25-turn trimpots for calibration adjustment - side adjustment is usually the better option as it means the unit can be more easily calibrated when connected to the rack's power bus.

The front panel PCB fits Alpha brand 9mm vertical-mount round shaft potentiometers, these are widely available from stores such as Thonk, Tayda, Smallbear, Mouser etc. The module should fit a number of different banana jack sockets, but the "correct" parts are the Cinch Connectivity range of jacks.

The intended knobs are Davies Molding parts - the 1913BW, 1910CS, and 1900H - though given the outrageous pricing of the actual Davies 1900H I'd strongly recommend using a good quality clone. Avoid the cheaper clones without an internal brass bushing - **Thonk** sells an excellent brass-bushed 1900H clone for a very reasonable price that I use in all of my own builds.

Alternatively, feel free to use any knobs that have similar diameters and will fit the Alpha round shaft pots. The Davies parts are 29mm, 19mm, and 13mm respectively, and many other manufacturers make knobs of similar sizes. The classic silver top Moog-style knobs actually work quite well also for the larger diameters.

CONSTRUCTION

The majority of construction can be performed like any PCB build, starting with the lowest-profile components (resistors and diodes) and working through to the taller ones (Capacitors, transistors, etc.). The simplest way to populate the board is simply to work through the BOM, doing each component type and value in one chunk before moving on to the next.

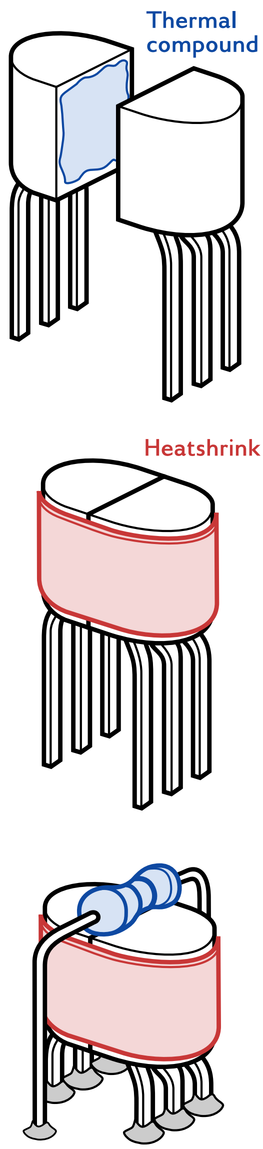
When soldering rectangular capacitors, I like to solder one leg on each, then hold the board in one hand while applying a *very* light pressure on top of the capacitor with a free finger, using the other hand to reheat the solder joint until the capacitor slides down tight against the PCB's surface. Continue this process for all the installed capacitors then go back and solder the remaining legs. This approach also works well to mount other components that need to mount securely onto the board, such as trimpots, IC sockets and pin headers.

Care must also be taken to ensure that the PCB-mounted potentiometers are mounted as vertically as possible on the board - one option is to click the potentiometers into place, then mount them to the front panel before soldering them. Also note that most potentiometers have a small anti-rotation tab on them that will need to be removed before soldering them into position, these can be cut off with a sharp pair of sidecutters, and I personally like to clean up any remaining protrusions with a few passes of a needle file as well.

The pin headers that interconnect the two boards are another component that needs a bit of additional care when assembling to ensure correct aligment. The best course of action is to solder one side of all the interconnects (either the pins or socket) into place, being careful to get them straight and flush with the board. Then connect the other halves onto them, lay the other PCB in place over the top (I would even recommend mounting the boards together with screws and spacers as they will be when finally assembled), and solder all the pins of the other side. Once they are all soldered, carefully separate the two boards, taking care to not bend the headers in the process.

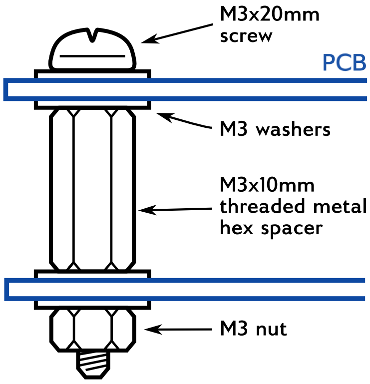
When fitting the matched transistors and tempco resistor (**if used**), these need to be thermally connected to ensure the best stability. The two BC560Cs should be joined face-to-face with a band of heatshrink tubing (I also like to smear a very thin layer of thermal compound between the two, making sure none gets near the conductive legs). Carefully bend the legs with a pair of tweezers so that they match the hole spacing on the PCB, and solder them into place. Once the transistors are installed, the tempco resistor can be mounted on top, using something like an epoxy or liquid electrical tape to keep it thermally coupled to the transistors and insulated from ambient temperature changes.

If using a BCM857DS instead of a matched BC550 pair, R310 should be mounted similarly in the alternate position over the BCM857DS IC, and ideally covered with some sort of insulating material as described above.

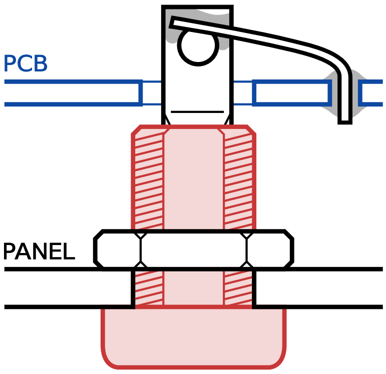


If you are going for full temperature compensation of the expo converter, it's recommended to thermally couple the matched transistors and tempco as shown and described in the text. If using unmatched transistors and a standard resistor, it is still worth heatshrinking the two transistors together, but the resistor dœs not need to be in thermal contact.

PHYSICAL ASSEMBLY



Connection of the two PCBs using standard M3 hardware. Washers are necessary on the inside to correctly space the boards for the interconnects. Screw head should go on panel side.



Connecting the banana sockets using an offcut component lead or similar.

Assembling the finished PCBs and front panel is very simple. Begin by fitting the M3 hardware to the panel-side PCB. screwing the hex spacer tight to hold it all together. Once all four screws are in place, start fitting the banana sockets into their respective holes on the front panel - making sure to align the flat terminals vertically (if using the Cinch-style sockets). The banana sockets need to be tightened solidly to prevent them coming loose in use, something like a dab of hot glue between the nut and thread can also help prevent loosening.

Make sure that the nuts and washers have all been removed from the PCB-mount potentiometers on the front panel PCB, as well as the anti-rotation tabs on the pots themselves (if present). Now you can join the front panel and panel PCB by pushing the pot shafts through their respective holes, fitting their washers and nuts, and tightening everything into place.

Now you'll need to connect the banana sockets to the front PCB using either some offcut component leads, or tinned copper wire. The simplest way is to solder the straight pieces of wire vertically into the pad on the PCB, then bend them over to meet the banana socket and solder that end to the flat side of the terminal. This way they can be easily disconnected for servicing by simply heating the terminal with the iron and pushing the wire away once the solder reflows.

Once the sockets are all connected, put M3 washers on all four mounting screws and carefully fit the second PCB into place - taking care to get the interconnects correctly seated. Until calibration is completed I would not fit the final washers and nuts to allow easy separation of the PCBs when troubleshooting, just making sure to take extra care plugging and unplugging the power connector when the PCB is unsupported.

When the module is confirmed to be working properly you can fit the final M3 washers and nuts and tighten up the whole assembly. Double check that the hex spacers haven't loosened in the meantime as well.

CALIBRATION

BEFORE YOU BEGIN

Before powering up the module for the first time, use a multimeter to check the resistances between the three power rails. Make sure that they show a resistance higher than 1KOhm, any lower and it's possible there is a short circuit or incorrectly oriented semiconductor somewhere on the PCB.

Calibration of the 2251 essentially consists of three overall operations: trimming out the offset of the filter core, setting the scale and offset of the exponential converter, and calibrating the extra VCA for maximum CV rejection.

The filter core offset adjustment is fairly trivial - with no signal connected to the input, measure the voltage at the bandpass output and then adjust the "OFFSET TRIM" trimmer (**RV201**) until the voltage reads 0v. There will often still be a small offset in the lowpass and highpass outputs after this, but zeroing the bandpass should ensure that the filter core's internal operation is centred correctly around 0v.

The VCA CV rejection adjustment is easily adjusted by ear using an oscillator or signal generator. First the audio input must be connected to 0v (as this input tends to float slightly when disconnected), this is easily accomplished by attaching an alligator clip jumper lead between one of the M3 screws connecting the boards and the rear terminal of the banana jack.

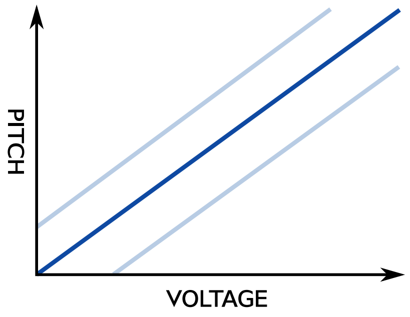
Once this is done, a squarewave signal around somewhere between 200-1000Hz and a suitable amplitude (ideally a 0-5v signal, but any audio signal under 10v peak-to-peak will be fine, like the squarewave output of a VCO) should be fed into the VCA CV jack and the output connected to a listening system. Simply adjust the "VCA CV REJECT" pot (**RV501**) until the output is as quiet as you can get it. Alternately this can be adjusted by eye using an oscilloscope.

While setting the scaling for the exponential converter is normally a fairly critical adjustment in something like a VCO, in the case of the 2251 it is much less important given that the frequency CV is also scaled by the input attenuverter.

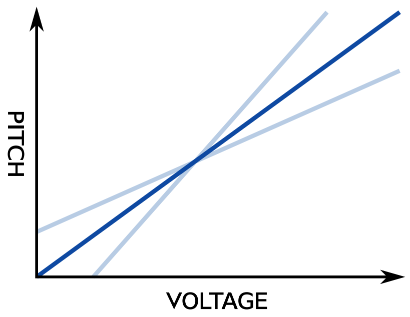
Adjustment of the exponential converter is achieved by setting the filter resonance to the point where the filter self-oscillates (making sure it's set high enough to oscillate at low frequencies as well), then adjusting the offset and scale trimmers while measuring the frequency with a frequency counter or tuning plugin etc.

Begin by setting the front knob to the "1.8k" mark and adjusting the Freq. Offset trimmer (**RV302**) so that the filter is oscillating close to 1.8kHz, then turn the

CALIBRATION



The CV Offset trimmer controls the overall offset of the filter's cutoff frequency for any given CV input or knob position.



The CV Scale control affects the scaling of the filters CV response in order to match the markings on the front panel. Because of the extra CV scaling by the input attenuverter, this dœs not need to be set to a precise 1V/Oct response as in a VCO.

knob down to the "150" mark and check the frequency there. Adjust the Freq. Scale trimmer (**RV306**) until the frequency reads around 150Hz, then go back up to the "1.8k" and again adjust the Offset trimmer to get the frequency to around 1.8kHz. Continue this process of adjustment until the frequencies at both these knob positions are around the right value, then check the other positions to see if they too output the correct frequencies.

The key thing to remember when making these adjustments is that the "1.8k" setting is close to the "centre" of the scaling, and so is not affected as much by the Freq. Scale trimmer, this is why we use the "150" mark to check the scaling and the "1.8k" to adjust the offset.

Don't worry too much about being super-accurate with this calibration, as most potentiometers like the one controlling the cutoff frequency will have a degree of inaccuracy and slop in them anyway, which can result in slightly different readings depending on which way the pot was turned to reach the current position and so on.

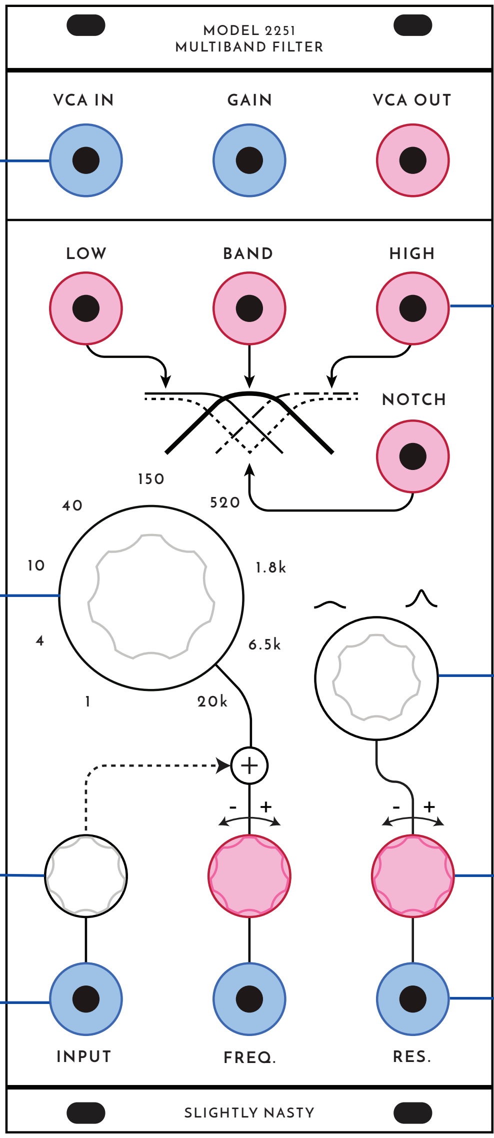
CONTROLS

VCA
Inputs and outputs for the Voltage Controlled Amplifier unit.

FREQUENCY KNOB
Sets the initial cutoff frequency of the filter.

AUDIO FM LEVEL
Controls how much the input audio signal modulates the filter

SIGNAL INPUT
The audio input to the filter.



FILTER OUTPUTS
Separate outputs for Lowpass, Bandpass, Highpass, and Notch filter bands.

RESONANCE KNOB
Sets the initial resonance level of the filter.

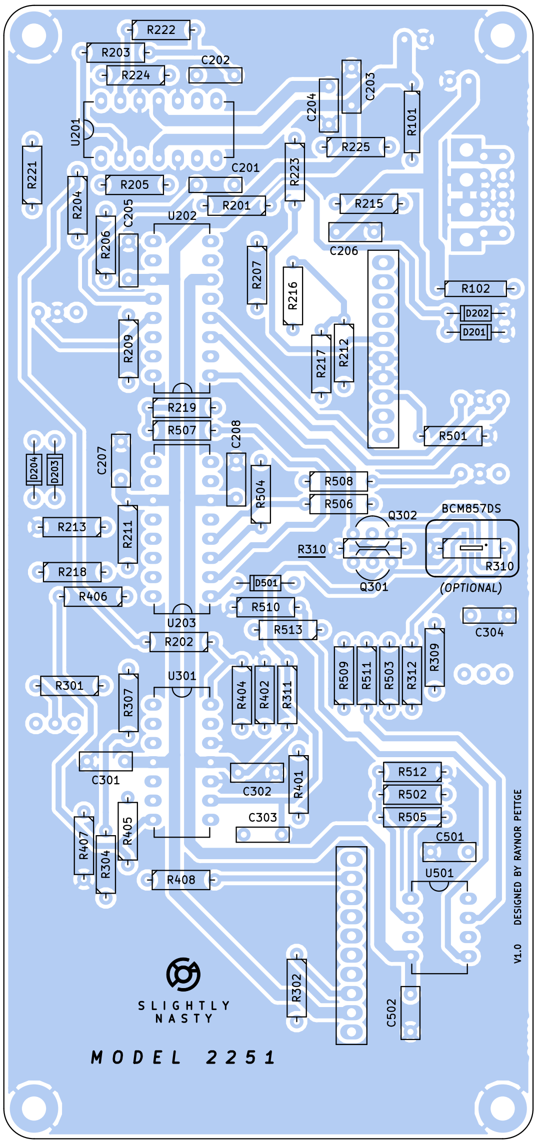
CV ATTENUVERTERS
Provide level and polarity control for the Frequency and Resonance inputs.

CV INPUTS
Frequency and Resonance CVs.

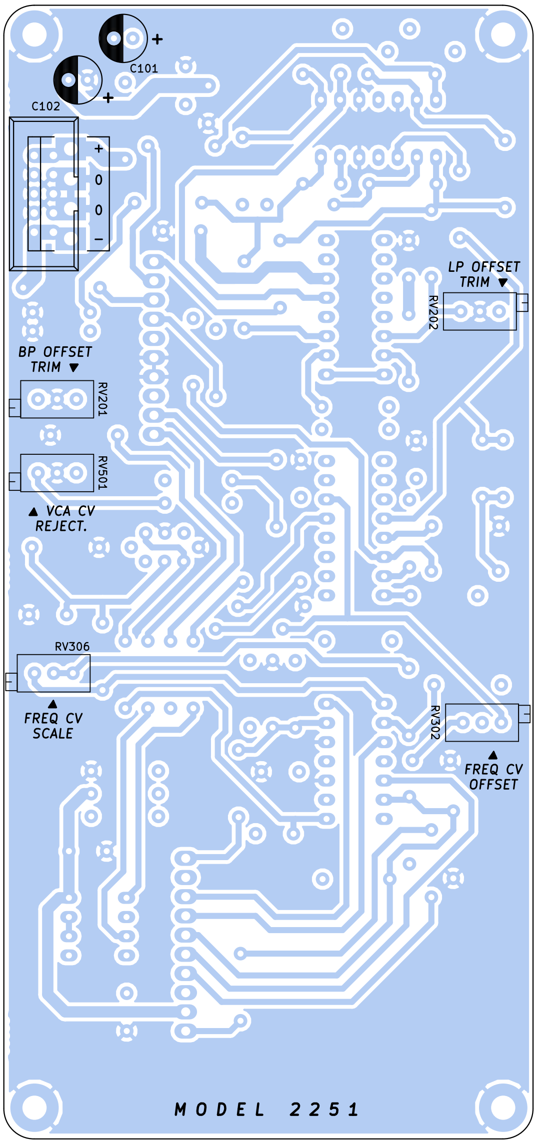
SLIGHTLY NASTY JACK COLOURS

RED	Bipolar signal output
BLUE	Bipolar signal input
YELLOW	AC-coupled input
BLACK	Logic output
WHITE	Logic Input

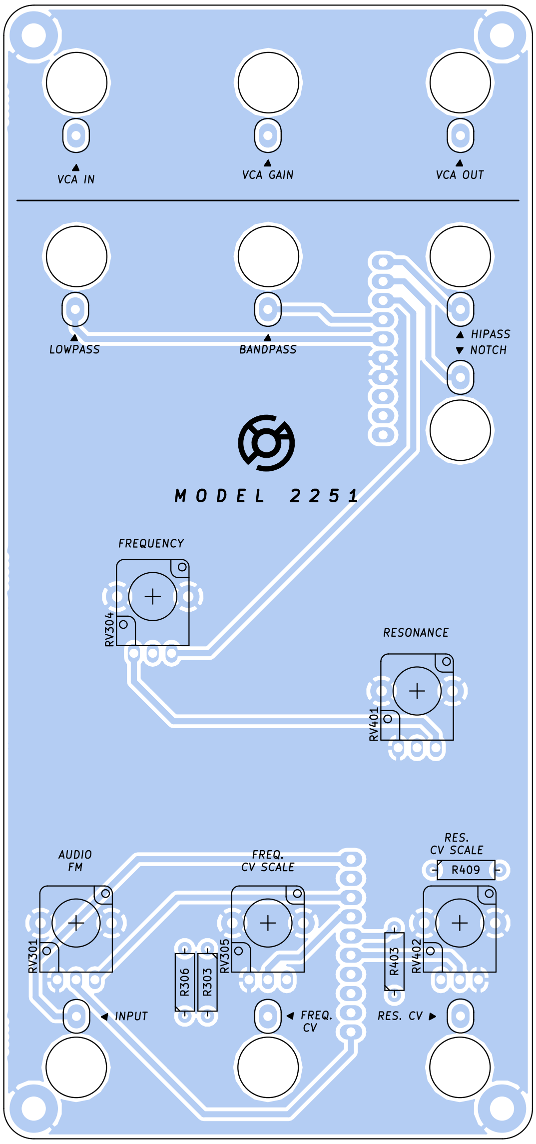
PCB GUIDE



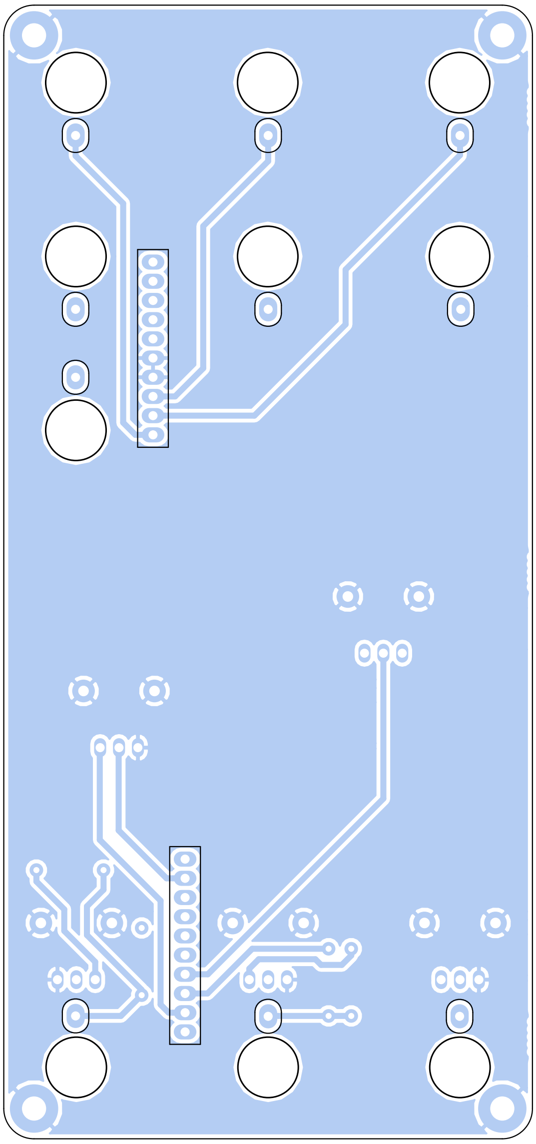
LOWER BOARD - TOP



LOWER BOARD - BOTTOM



LOWER BOARD - TOP



LOWER BOARD - BOTTOM

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