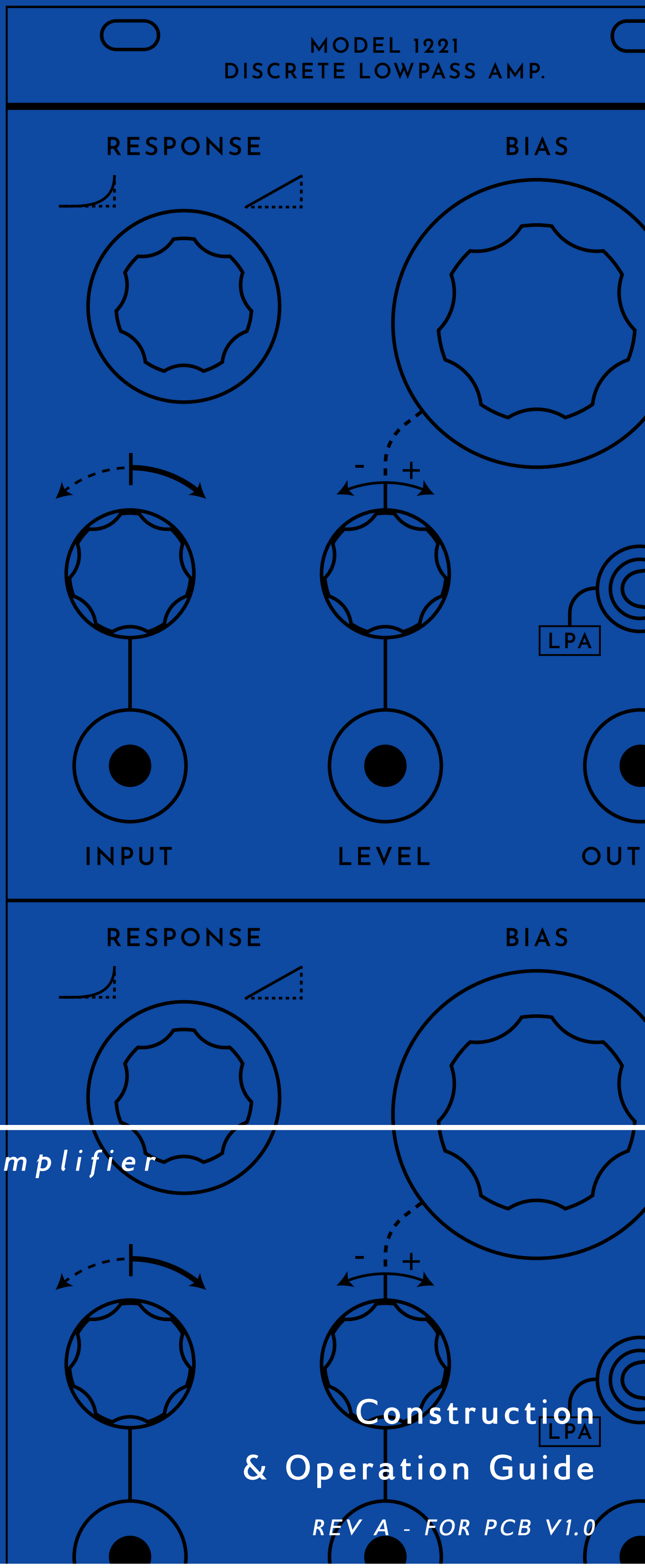
MODEL 1221

Discrete Lowpass Amplifier

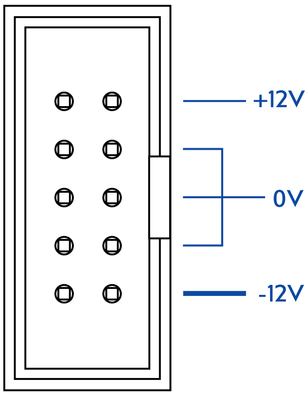


Construction & Operation Guide

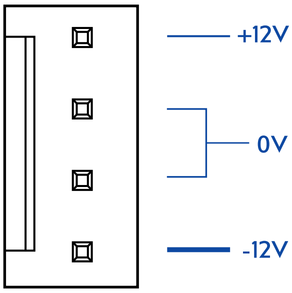
REV A - FOR PCB V1.0

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:	~35mm from rear of panel
PCB:	70 x 75mm (Upper)
CONNECTORS:	4mm Banana

ELECTRICAL

POWER:	+12V, 0V, -12V
CONSUMPTION:	~15mA +12V Rail, ~5mA -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)

INPUT:	+/- 5V
LEVEL:	+/- 5V

OUTPUT RANGES (nominal)

OUTPUT:	+/- 5V

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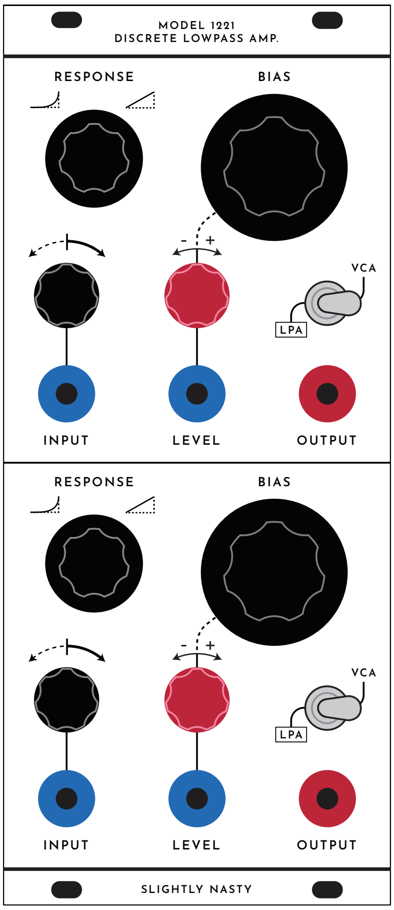
INTRODUCTION



The **Slightly Nasty Model 1221 Discrete Lowpass Amplifier** is a dual discrete-transistor VCA that offers the choice of either traditional VCA operation, or "Lowpass Amplifier" mode - where the amplifier also lowpasses the signal with cutoff frequency tied to the signal gain. This is accomplished by adding a 12dB/oct transistor-ladder filter stage to the top of a classic differential-pair VCA circuit, creating a circuit that varies both amplitude and bandwidth of the signal with a single control current.

The CV input features both an attenuverter and a variable response curve which is continuously adjustable between linear and exponential. The signal input has a level control that allows for greater-than-unity input, to allow the discrete VCA core to be overdriven and take advantage of the inherently smooth distortion characteristic of this type of circuit.

A large Bias knob is provided to manually open the VCA, allowing for manual performance, or reverse operation in conjuction with the CV attenuverter when doing things like sidechaining or compression effects, among others.

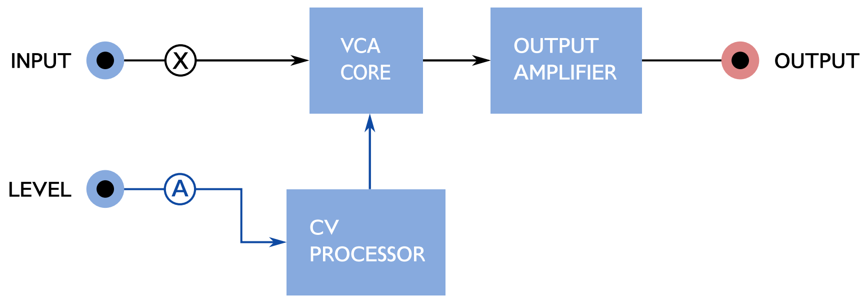
The Lowpass Amplifier mode is great for mimicking the natural effects of distance on a sound, where the high-frequency content fades with distance more quickly than the lows. It can also add a slightly more organic quality to sounds, making their harmonic complexity increase in intensity as they get louder. Another use case is creating simple synth parts without tying up a dedicated VCF module - great for adding little extra elements to a patch.

CIRCUIT OVERVIEW

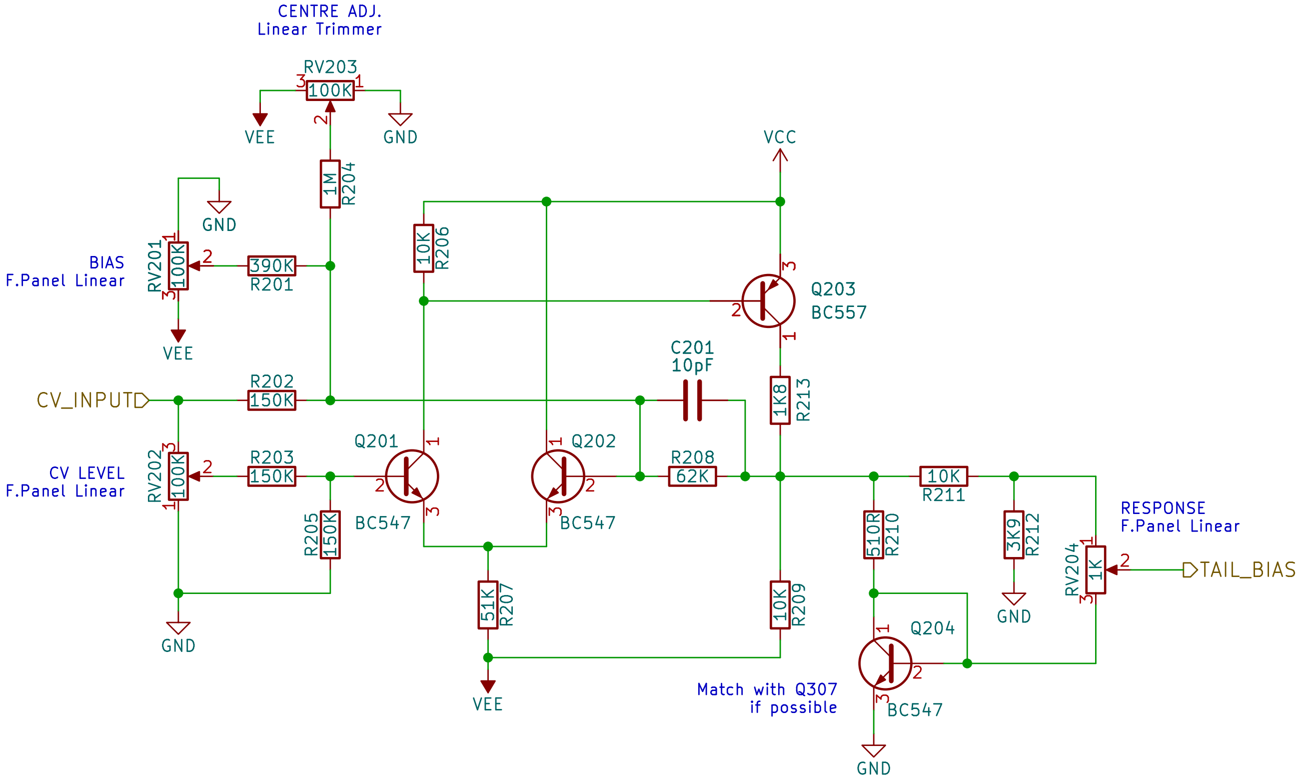
For full schematics, please download the separate schematics PDF. Excerpts shown in this manual may be outdated and are provided for reference only.

The Model 1221's circuitry can be broken up into three main subsections:

1. **CV processor / Attenuverter** - This is the circuit that applies attenuverter scaling to the CV input jack, mixes it with the Bias knob setting, and feeds the result into the linear/exponential control circuit. It also allows for trimming the 'dead zone' of the VCA's response.
2. **VCA / LPA Core** - This circuit provides the actual voltage-controlled gain functionality, via a classic differential pair VCA core to which a two-stage transistor ladder is attached. The front panel mode switch switches the filter capacitors in or out to enable and disable the filter.
3. **Differential Amplifier** - This takes the differential output of the VCA and converts it into a single output signal, amplifying it back to modular level and cancelling out the signal offset caused by the control current.



Block diagram of the Model 1221. Circles marked "A" are attenuators. Circles marked "X" are attenuverters.



Circuit Overview

CV PROCESSOR

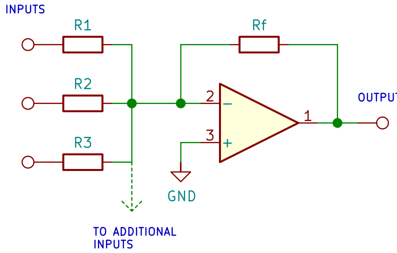
The CV processor in the 1221 serves a few different purposes - it provides attenuverter functionality for the LEVEL CV input, combines it with the voltages from the BIAS knob and the trimmer potentiometer, and then creates the linear and exponential response voltages that the RESPONSE control sweeps between.

While it may not be obvious at a glance, this circuit is actually based around an opamp - formed by transistors **Q201**, **Q202**, and **Q203**. The first two form a differential pair by sharing a common emitter resistor (**R207**), providing the positive and negative inputs needed for our opamp. **Q203** is controlled by the voltage across **R206** (proportional to the current passed by **Q201**), which it amplifies without any emitter feedback - meaning that it would normally increase the gain as much as it possibly can until it inevitably clipped. However because we have the second transistor **Q202** providing our negative input, we can feed the output voltage across **R209** back into the opamp as negative feedback, with the value of the feedback resistor **R208** determining the gain of the whole system in relation to the input resistor values.

If you've seen these sort of opamp circuits before, you might be wondering what the strange-valued resistor **R213** is doing, stuck between **Q203** and the output node. This has been added to force the opamp to clip at a much lower voltage that it would normally, to prevent the VCA core from being overdriven by excessive current (as would happen by putting the BIAS control to maximum and then inputting a +5V CV signal at the same time, for example).

The attenuverter functionality is accomplished by using the CV LEVEL pot to sweep the opamp between inverting and non-inverting configurations for the CV input signal, just like in a typical IC opamp attenuverter. The BIAS and trimmer potentiometers are just connected as inverting inputs through the input resistors **R201** and **R204**, which set their respective influences on the final output of the opamp.

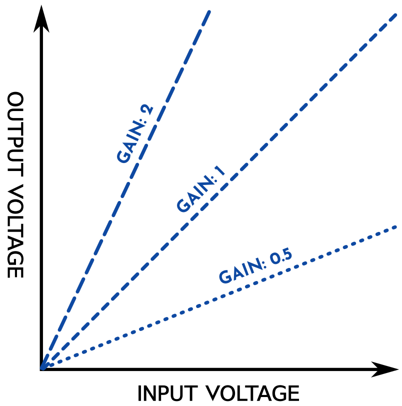
The circuit around **Q204** is the linear-exponential response network, which generates two voltages - one is a "linear response" voltage created by using R210 and **Q204** as the front half of a current mirror, and the other is an "exponential" voltage which simply divides the input voltage down a bit and sends it through to the RESPONSE pot. This might seem a little confusing at first, as the "linear" voltage actually ends up being a logarithmic relationship to the input, while the "exponential" voltage is actually linear! The key is realising that these voltages are being sent to the current source transistor **Q307** in the VCA core, which is operating without feedback in its exponential region (0 to ~0.7V), so the actual final current that it passes through the VCA core will end up being correct (linear or exponential response) when these voltages are applied to its base.



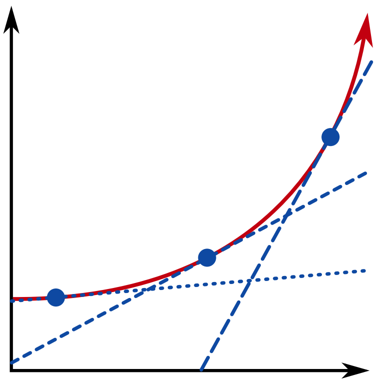
Typical topology of a summing amplifier. The negative feedback through Rf cancels any voltage shift at the opamp's inverting "-" input and thus holds it at the same voltage as the non-inverting "+" input. This means that each input signal sees only a resistor connected to 0v, even though multiple input signals are connected to the same circuit node.

One way to think of this is that the signals are each converted into a current by the input resistors, and the opamp adjusts the current through Rf to make it equal to the sum of all the input currents. As the same current is flowing both into and out of the node connected to the opamp's inverting input, the voltage at that point cannot change.

VCA CORE



Different signal gains plotted as output voltage relative to input voltage.



Tangent lines showing how different points along an exponential curve can approximate these gain relationships.

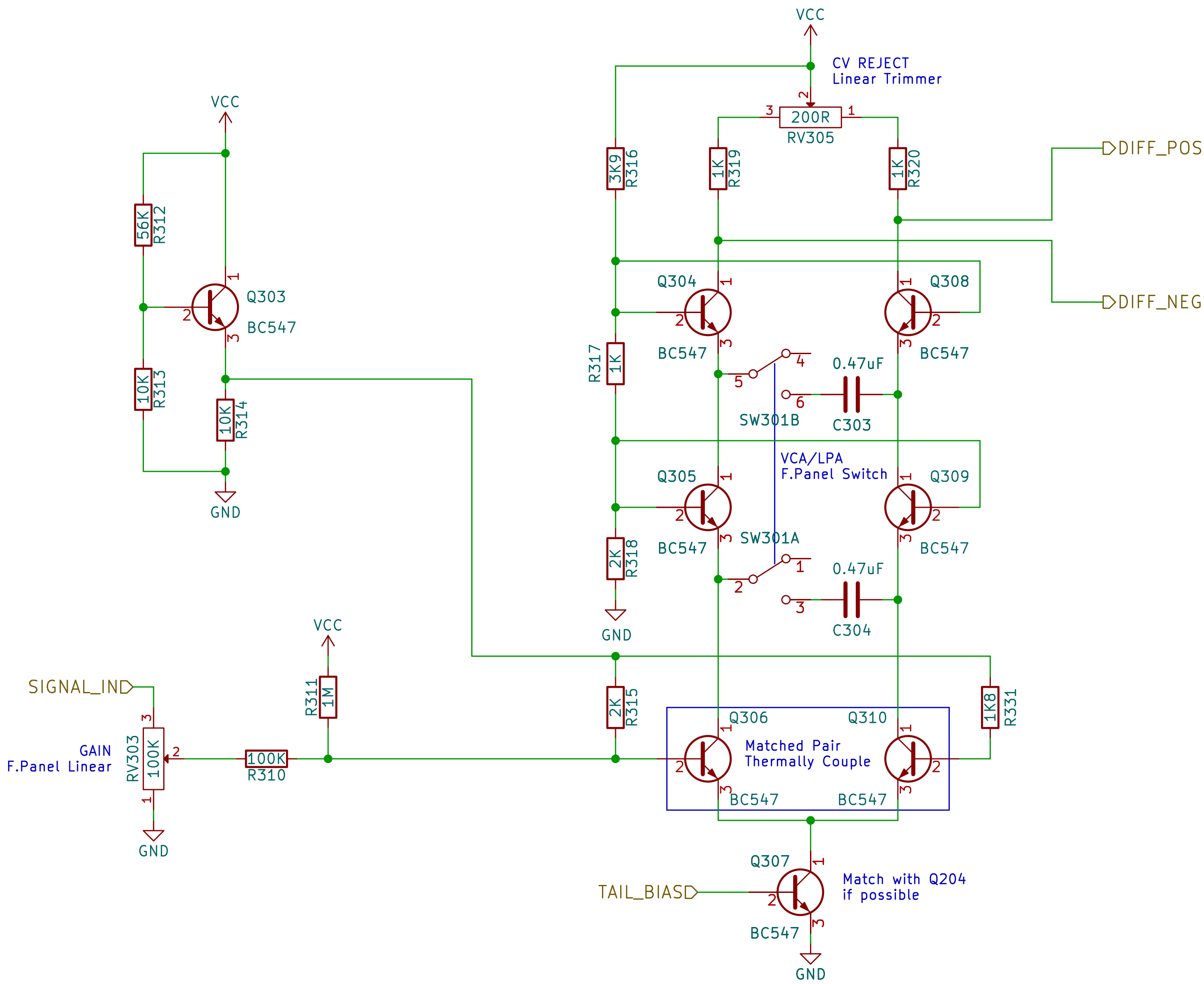
The VCA core in the 1221 is based around a classic discrete transistor differential pair circuit - comprised of input transistors **Q306** and **Q310**, and the current source transistor **Q307**, which controls the current that is pulled through the VCA core, and consequently the gain of the output. If you're not familiar with transistor circuits like this, it might not be obvious how this arrangement is able to create variable gain, but the secret is in the way that transistors behave at low base-emitter voltages (<0.7V or so). In this region of operation the relationship between the input (base-emitter) voltage and the output current is actually an exponential curve - meaning that as voltage increases, so dœs the *slope* of the current output response.

This becomes significant when you consider what gain actually means - if we plot input level against output level as a graph, then clearly unity gain will just be a straight line going from 0 to 1 diagonally across the graph, with a slope of 1. If we have 2x gain, then the line will go from 0 to 2 at a steeper diagonal, with a slope of 2. Obviously for a gain of one half, the slope of the response line is 0.5.

The practical issue here is that while we want a series of nice straight response lines for our various gain amounts, what we have in reality is a single, curved exponential line. But the thing about continuous curves is that any of them can become "straight" - you just have to zoom in enough! This is why VCA and filter circuits often require the input signals to be severely attenuated before they hit the input - we need them to be small enough to map onto our exponential response curve without there being a significant amount of curvature within the voltage range of the signal. Or as you and I might call it - distortion. This restricts the signal level in these sort of circuits to the few tens-of-millivolts range typically.

If you've followed along with all that, then you might have spotted another problem with this whole arrangement - in order to make use of the various slopes across the transistor's response curve, we need to add a significant voltage offset to our signal in order to place it on the curve where we need it. This is why the circuit is based around a differential pair - using this setup we can essentially perform the variable gain trick twice - on a inverted and uninverted copy of the signal, and then by subtracting those two from each other we can cancel the offset voltage while adding the signal components together. (Note that in practice we don't actually directly add this offset to the input - we actually "move" the response curve itself by varying the emitter current of the transistor).

The differential amplification trick has another benefit too - the inherent distortion on our two signals, the "bend" caused by the not-perfectly straight response curve, will also appear to be in the opposite direction for each of the signals and will similarly cancel.

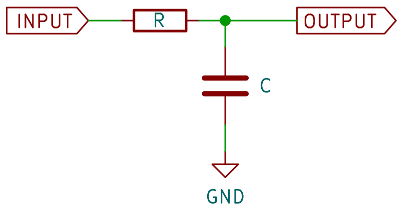


Q303 provides biasing for the VCA transistor pair, by buffering a simple voltage divider (**R312**/**R313**) and feeding it to the transistor bases.

The value of the filter capacitors in this circuit are a compromise between having the high frequencies open up sufficiently at maximum gain, and having audible filtering action at medium and low-gain settings. Because the human ear is far more sensitive to the action of a lowpass filter in the middle and low-frequency ranges, setting a low enough capacitor value to have the top end open up fully results in significantly audible filtering only beginning to occur as the signal level drops into inaudible volume levels (particularly in the context of a busy mix/ patch). The 470nF value was chosen after trialling a few different values, as it provided the best compromise to my ear.

The loss of some high frequencies even with the amplifier at max is a common complaint with Lowpass Gate / Lowpass Amplifier type circuits, though I've rarely found it a problem in actual use - a signal that's being used for top-end sounds in a patch is usually not going to be using the Lowpass mode anyway.

FILTER LADDER



A basic passive RC lowpass network. In the 1221, the ladder transistors serve as variable resistance sources instead of the resistor R, and the capacitors connect between the two sides of the ladder instead of to ground.

The filter stage of the Model 1221 consists of a 2-pole transistor ladder grafted to the top of the VCA transistor pair. The working principle of the ladder filter can be analysed in a few different ways, but one of the simplest is to think of each stage as being a current-controlled RC lowpass network like the one illustrated on the left. The transistors function as variable resistors using exactly the same principles discussed in the previous section, controlled by the same control current that passes through the VCA pair. The capacitors are connected across the ladder so that the two copies of the signals (inverted and non-inverted) can share the one filter capacitor for each stage, halving the number of capacitors needed and removing the need to precisely match capacitor values for each side of the ladder.

This network of resistors connected to the bases of the transistors bias them to provide separation between the individual stages of the filter network, preventing them from interacting with one another like a cascaded pair of passive RC network would. (The forward diode drop of the transistors also naturally provides some isolation).

By switching the filter caps in and out of the circuit, we can switch between VCA and Lowpass Amp modes. The current signals at the top of the ladder are converted to voltages by **R319**/**R320**, with **RV305** allowing a small adjustment of the relative voltage levels of each to correct for imbalances caused by component tolerances etc.

OUTPUT AMPLIFIER

The output amplifier in the Model 1221 is based on another three-transistor opamp, as in the CV processor circuit, but this time with an additional output stage to provide more power and consistency of behaviour when connected to various module inputs.

The main part of the circuit - **Q411**, **Q412**, and **Q413** - form the opamp stage, which is configured as a differential amplifier with the gain being determined by the relative resistance between the input resistors (**R421** and **R425**), and the resistors **R422** and **R426**. This time the output transistor **Q413** dœsn't directly provide the output voltage, but instead drives a class AB output stage consisting of a complementary pair of NPN and PNP transistors (**Q414** and **Q415**) operating as emitter followers, and biased to minimise crossover distortion by the diodes **D403** and **D404**.

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*(Quantities listed are for **one** PCB)*

RESISTORS			
10R	2	R106, R107	*All 1% Metal Film*
510R	2	R210, R429	
1K	3	R317, R319, R320	
1K8	2	R213, R331	
2K	2	R315, R318	
3K9	2	R212, R316	
10K	7	R206, R209, R211, R313, R314, R403, R424	
33K	2	R421, R425	
51K	3	R207, R402, R423	
56K	1	R312	
62K	1	R208	
100K	3	R310, R422, R426	
150K	3	R202, R203, R205	
390K	1	R201	
1M	4	R204, R311, R401, R428	
Do Not Fit	**1**	**R301**	

CAPACITORS			
10pF	2	C201, C405	*Ceramic or Mylar Film*
0.68uF	2	C303, C304	*Mylar Film, 5mm pin pitch*
100uF	2	C101, C102	*Electrolytic >16V, 2.5mm pin pitch*

SEMICONDUCTORS			
1n4148	2	D403, D404	
BC547C	14	Q201, Q202, Q204, Q303, Q304, Q305, Q306, Q307, Q308, Q309, Q310, Q411, Q412, Q414	*Q204/Q307 and Q306/Q310 should be matched pairs if possible*
BC557B or C	3	Q203, Q413, Q415	

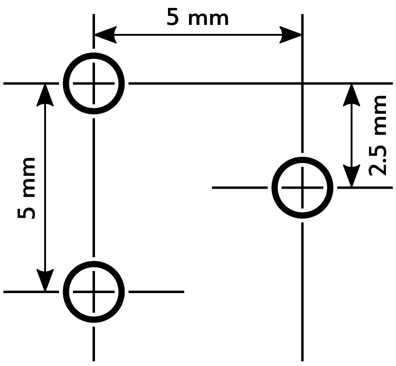
POTENTIOMETERS			
100K	3	RV201, RV202, RV303	*Alpha-style 9mm PCB mount*
1K	1	RV204	*Alpha-style 9mm PCB mount*
200R **Trimpot**	1	RV305	*6mm horizontal PCB mount trimpot*
100K **Trimpot**	2	RV203, RV401	*6mm horizontal PCB mount trimpot*

ELECTROMECHANICAL			
DPDT **On-On**	1	SW301	

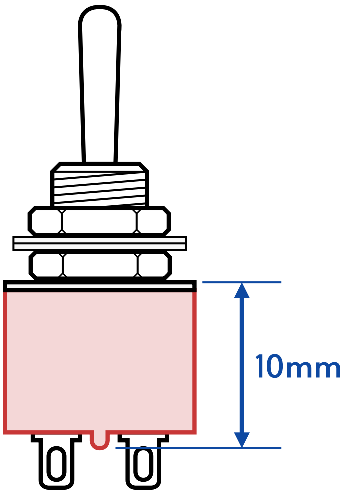
CONNECTORS			
10-pin 2.54mm Pin Header	4		
10-pin 2.54mm Female Pin Header	4		
10-pin IDC Header **OR** 4-pin MTA-156	1		
Banana Socket Blue	2		
Banana Socket Red	1		

MECHANICAL			
M3 x 20mm Screw	2		
M3 Washer	8		
M3 x 10mm Threaded Metal Hex Spacer	2		
M3 Nut	2		

CHOOSING COMPONENTS



The mini trimpots should match the footprint shown here.



The height of the switch body before installation must be 10mm from the top of the body to the bottom of the moulded ridge that runs between the pins. On some switches this ridge may need to be filed down slightly with the edge of a flat needle file or similar.

Like all Slightly Nasty modules, the Model 1221 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 mylar film types.

The transistor pair **Q306** / **Q310** should be matched for maximum CV rejection , the Model 1011 Discrete Oscillator manual contains a section on how to match transistors using the Ian Fritz method. This is not as critical as for a VCO application, so typically just selecting the best matching pair out of a few candidates is usually sufficient.

It's also a good idea to match the current mirror pair **Q204** / **Q307** in order to keep the maximum gain levels the same between the linear and exponential response modes.

The DPDT On-On switch should be available at most decent suppliers, the main thing to note is that the top of the switch body (the part that sits against the front panel, needs to be 10mm from the top of the PCB when the switch is soldered into place. On some switches (such as those sold at **Tayda**) this will mean using a small file to file down the plastic ridge that runs between the solder terminals.

The trimmers for the gain and offset trimming are standard top-adjust mini trimpots (sometimes referred to as 6mm trimpots), which use the footprint shown on the left.

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

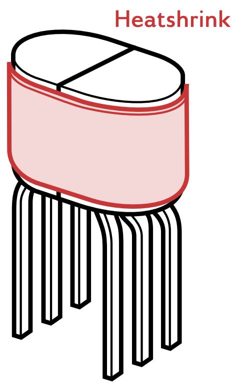
The majority of construction can be performed like any PCB build, starting with the lowest-profile components (resistors and diodes) and working through to the taller ones (Capacitors, transistors, etc.). The simplest way to populate the board is simply to work through the BOM, doing each component type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

When soldering transistors, my preferred approach is to populate the board with all the transistors of the same type, then solder only the centre leg of each one. The board can then be flipped over and all the transistors straightened up using tweezers before soldering the remaining legs. Generally I prefer to only solder one leg at a time on each transistor to avoid overheating the part, so that they have time to cool down between soldering operations. Note that the VCA transistors should be physically coupled as illustrated on the right.

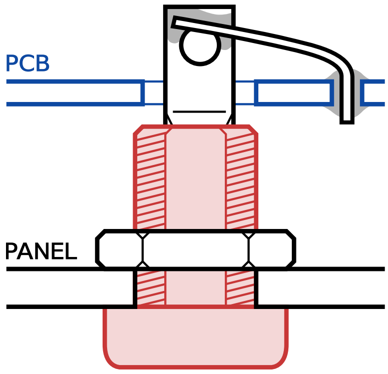
Care must also be taken to ensure that the PCB-mounted potentiometers are mounted as vertically as possible on the board - one option is to click the potentiometers into place, then mount them to the front panel before soldering them. Also note that most potentiometers have a small anti-rotation tab 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 DPDT mode switch in the 1221 is probably the component that requires the most attention during construction . As mentioned in the "Component Selection" guide on the previous page, the switch itself must first be checked for correct height when mounted to the board. Soldering the switch into place should always be done with the face panel temporarily attached in order to ensure it is vertical, which means it should be left until after the potentiometers have been soldered in.



It is recommended to use heatshrink to thermally couple the VCA transistor pair Q306 / Q310 to keep the CV rejection constant with temperature changes.

PHYSICAL ASSEMBLY



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 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 potentiometers on the PCB, as well as the anti-rotation tabs on the pots themselves (if present). Now you can join the front panel and 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 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 melts.

CALIBRATION

Calibration of the 1011 consists of adjusting the three calibration trimpots on the back of the module to set the following values (in order):

1. **CV Reject** - Adjusts the balance of the two sides of the VCA/filter core to ensure complete cancellation of the CV signal.
2. **CV Centre Adjustment** - Moves the circuit's CV response up or down to allow the minimum (off) gain setting to completely block the input signal without bleed.
3. **Output Offset** - Allows any DC voltage offset present at the output to be removed.

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.

CV REJECT

To adjust the CV rejection, first turn the "INPUT" attenuation knob fully counterclockwise in order to ground the input to 0V. Also set the "BIAS" knob to its lowest setting, and the "RESPONSE" knob to the linear mode (fully clockwise).

Turn the "LEVEL" knob to maximum and connect a +/-5v squarewave oscillator signal to the LEVEL input jack. You can just use the output from one of your VCOs for this, with the frequency set to some middle position. Connect the output to whatever monitor/speaker setup you have so that you can hear it - you will probably hear the squarewave signal at this point.

Adjust the "CV Reject" trimmer until the volume of the squarewave is as low as you can possibly get it - there should be a fairly clear point in the trimmer's range where the volume dips significantly.

CV CENTRE ADJ.

To set the CV centre adjustment, disconnect the squarewave signal used in the previous step from the "LEVEL" jack and connect it to the "INPUT" jack instead. Set the "INPUT" knob to noon and make sure the "BIAS" and "RESPONSE" knobs are still set as before.

Listen to the output signal as you adjust the "CV Centre Adj." trimmer, the goal is to set this so that the input signal just becomes inaudible. You don't want to set it too low, otherwise you will have a "dead zone" at the bottom of the gain range where the VCA stays switched off even with a CV signal applied. too high and you'll hear some of the input signal bleeding through even with the VCA set to its minimum.

It's not a bad idea to listen to this with the volume turned up quite high on your monitoring setup - or even listening through some overdrive/distortion so that you can really hear where the bottom of the range is. Sometimes when setting by ear at normal listening levels you can end up leaving a little bit of bleed that becomes audible later when using significant overdrive/distortion in a patch.

OUTPUT OFFSET

The Output Offset trimmer allows any small static voltage offset at the output to be nulled out. To set it, disconnect the INPUT and LEVEL jacks, and turn the "INPUT" and "BIAS" knobs down to their minimum. Connect a multimeter between a 0v point (the mounting screws are good for this) and the output jack,, and with the multimeter set to the millivolt range adjust the Output Offset trimmer until the voltage reading is as close to 0v as you can get it.

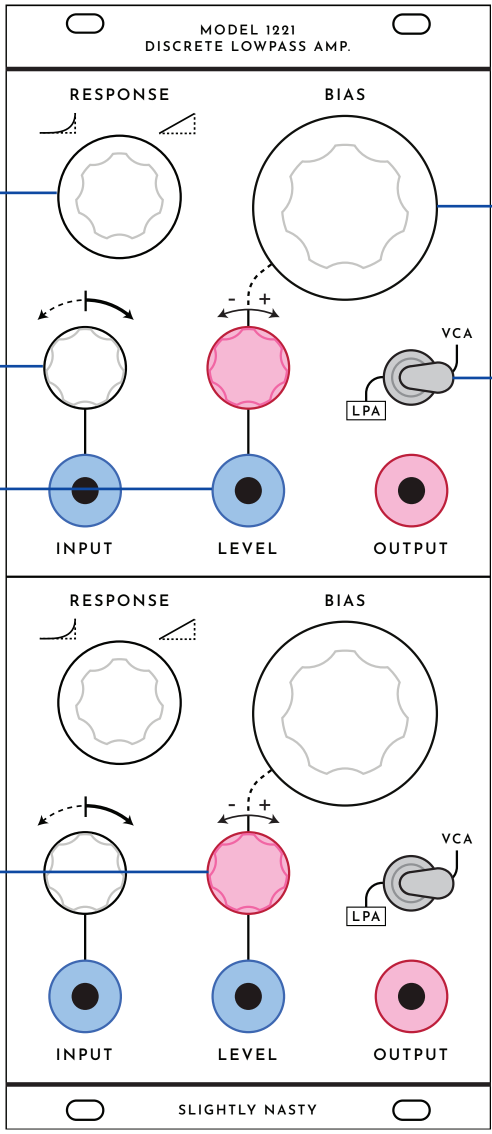
CONTROLS

RESPONSE KNOB
Continuously adjusts the CV response between exponential and linear

INPUT LEVEL
Centre position is unity (1:1), turning further right allows the amplifier to be overdriven.

LEVEL INPUT
CV input for the amplifier

LEVEL ATTENUVERTER
Allows the amount of CV sent to the amplifier to be adjusted between -100% and +100%, with 0% at centre.



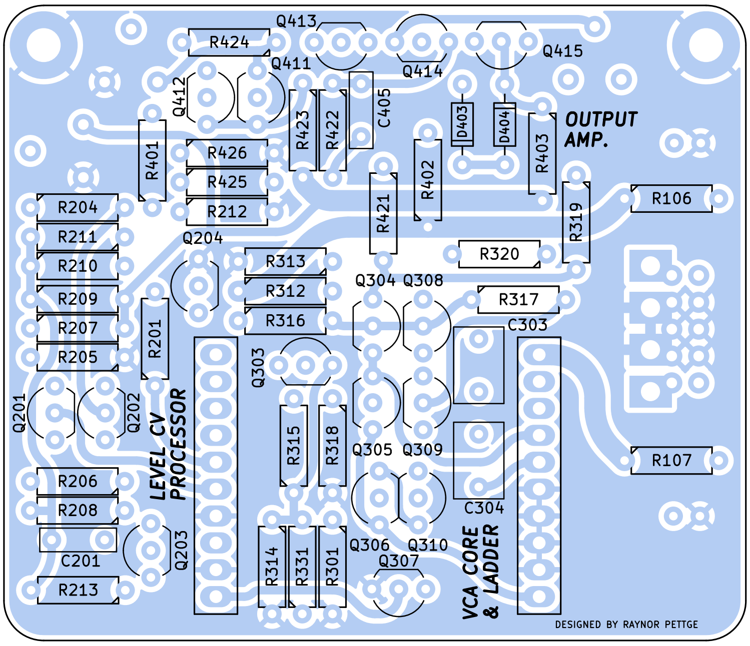
BIAS KNOB
Allows the amplifier to be opened manually - the CV is added to or subtracted from this setting.

MODE SWITCH
Switches operation between VCA and LPA modes.

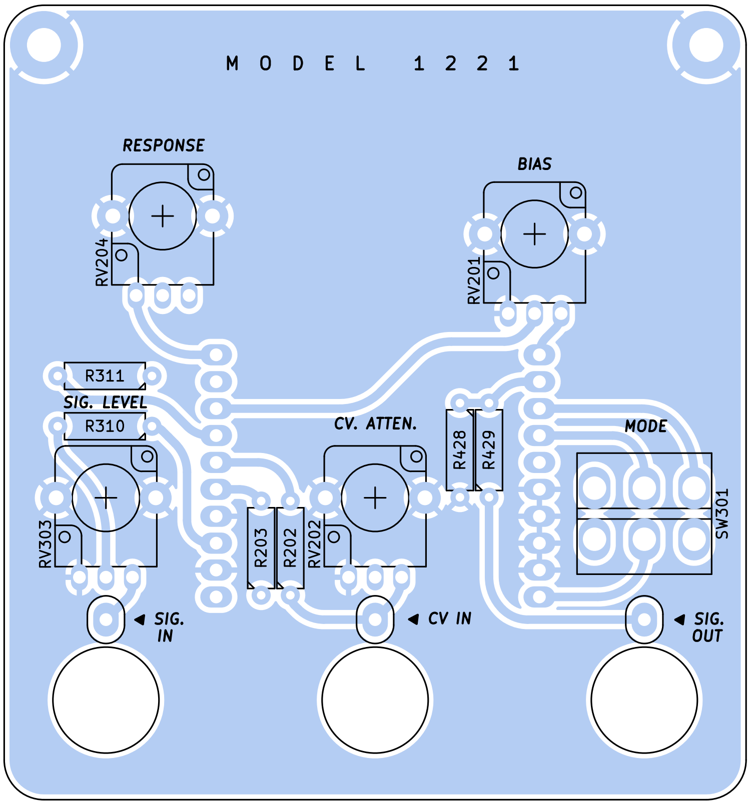
SLIGHTLY NASTY JACK COLOURS

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

PCB GUIDE

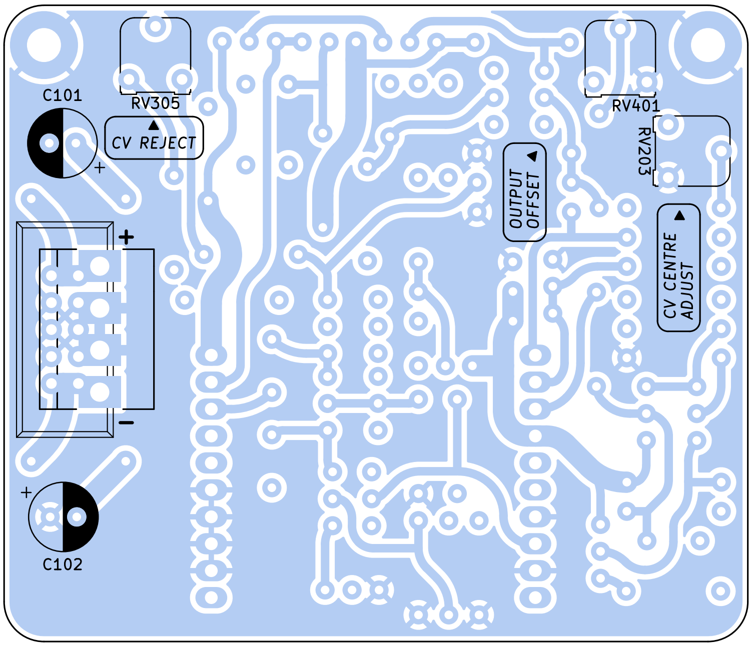


LOWER BOARD - TOP

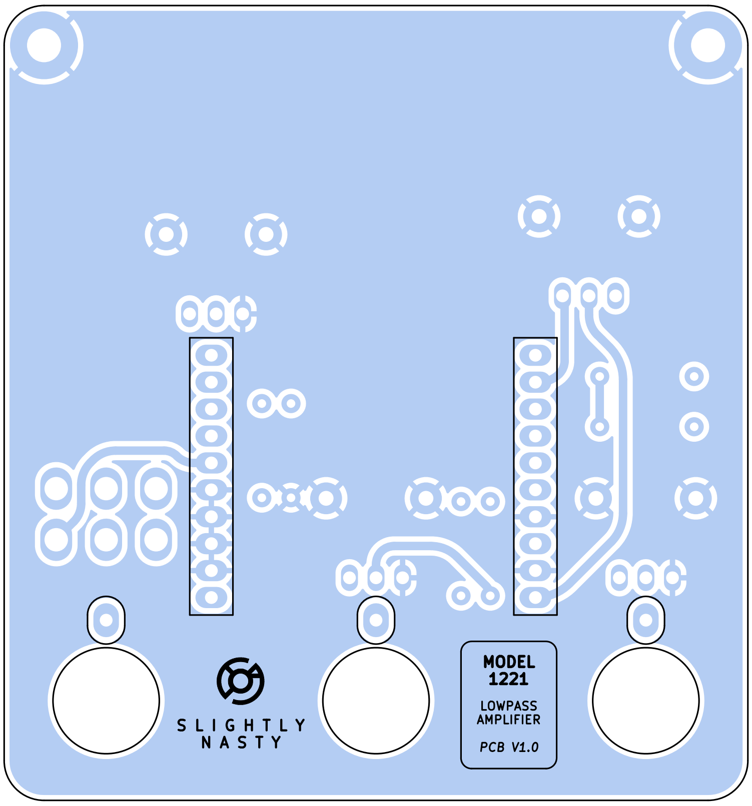


UPPER BOARD - TOP

PCB GUIDE



LOWER BOARD - TOP



UPPER BOARD - BOTTOM

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