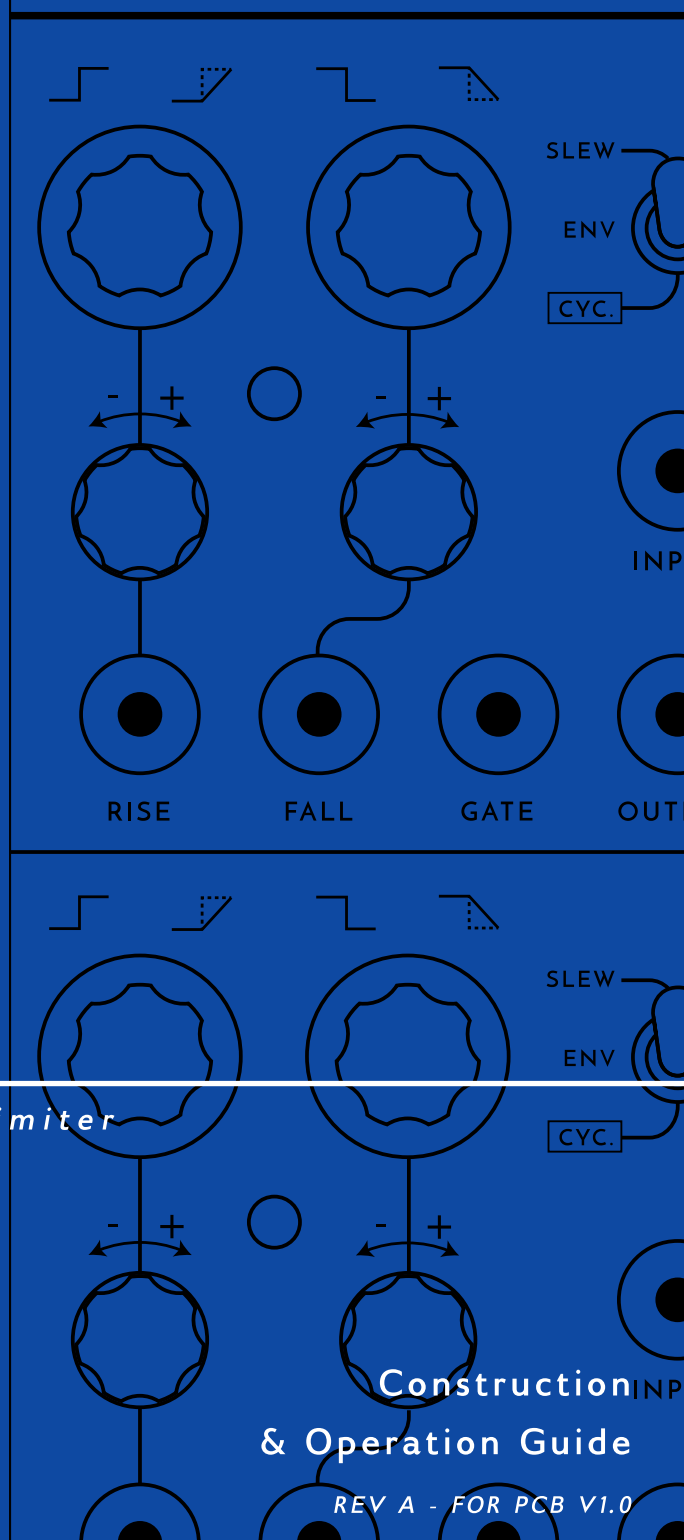




MODEL 2231

*Asymmetric Slew Limiter*

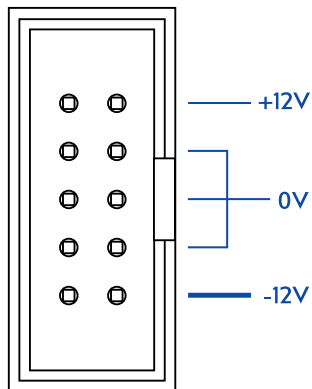
MODEL 2231  
ASYMMETRIC SLEW LIMITER



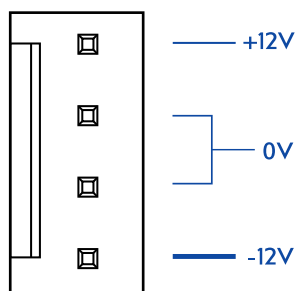
Construction  
& Operation Guide

REV A - FOR PCB V1.0

## 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:	~40mA +12V Rail, ~30mA -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)

SIGNAL:	+/- 5V
RISE:	+/- 5V
FALL:	+/- 5V
GATE :	0 - 5V

### OUTPUT RANGES (nominal)

OUTPUT (SLEW):	+/- 10V
OUTPUT (ENV):	0 - 5V
OUTPUT (CYCLE):	+/- 5V

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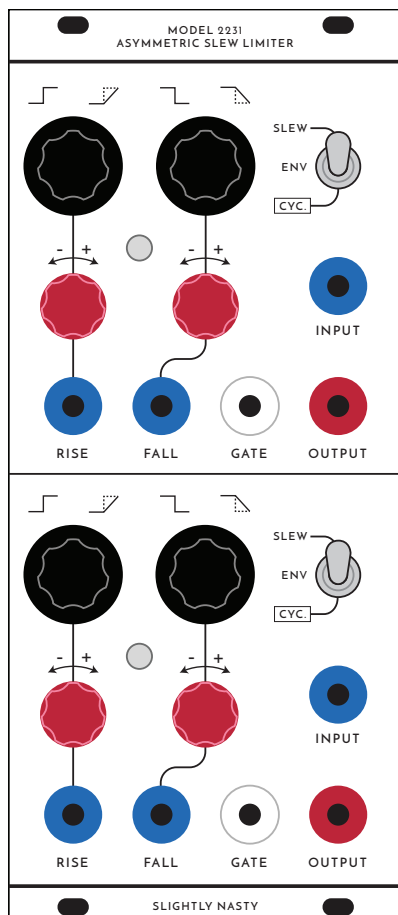
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## INTRODUCTION



The **Slightly Nasty Model 2231 Asymmetric Slew Limiter** is a versatile signal generator and signal processor based on the principle of the **Universal Slope Generator** originally found on **Serge** synthesisers. This style of module is often seen as one of the defining elements of the "West Coast" school of synthesiser design, with its emphasis on open-ended versatility and functional abstraction.

Essentially the Model 2231 is a voltage-controlled integrator, with a few additional circuits that allow it to be used for a number of other functions. The basic principle behind the module is that there are actually quite a few synthesiser circuits that are based internally around some kind of integrator - the Model 2231 takes this central core and presents it in a way that allows it to be used in several different configurations.

There are three operating modes on the Model 2231. "**SLEW**" takes the incoming signal and slews it according to the rise and fall rates set by the panel controls and CVs. At longer slew times, this can be used as either a traditional slew processor for portamento effects, or to add attack and release times to a gate signal, like an AR envelope generator. At higher (audio) rates, the 2231 can operate as a voltage controlled lowpass filter, with the added trick of being able to have different cutoff frequencies for the rising and falling parts of the waveform. This can yield an interesting combination of filtering and waveshaping.

"**ENV**" turns the 2231 into a voltage-controllable AD envelope generator, triggered by the positive edge of a gate signal. The envelope is auto-completing and retriggerable (on the decay portion), and voltage control of the attack and decay times can provide some nice modulation options to add variation to sequences.

"**CYCLE**" turns the 2231 into an oscillator (or LFO) with a range of around 0-1kHz, with independently controllable rise and fall rates allowing for some interesting waveshape and pitch modulation. Using one subunit of the 2231 as an LFO to modulate the rise/fall times of the other allows for some interesting rhythmic effects and is an easy way to add movement to a patch.

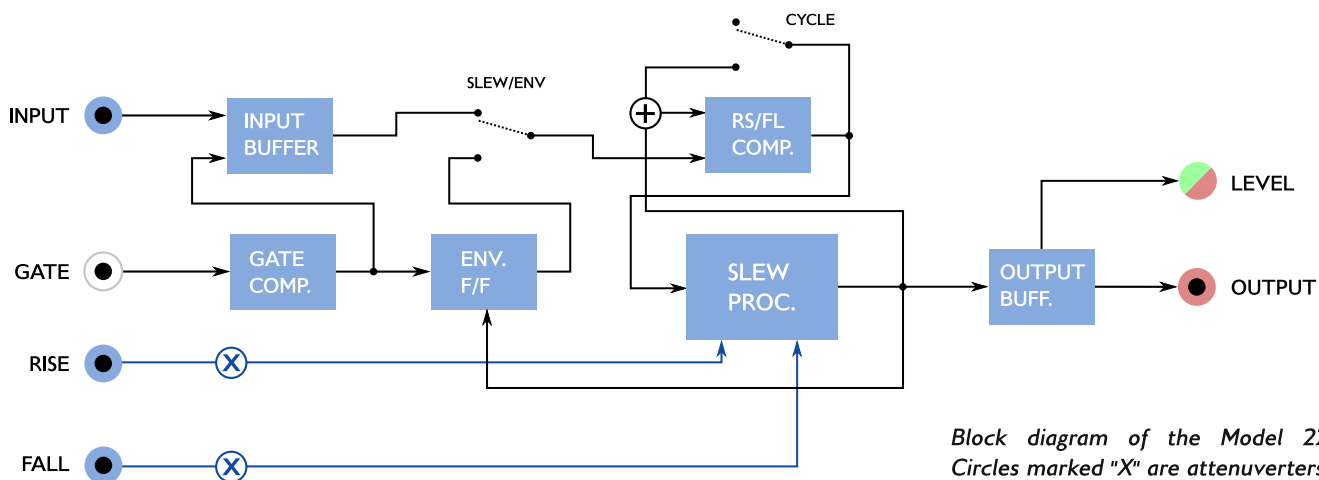
The slope times have a logarithmic response extending from "As slow as you trim it" to around 1 millisecond for a -5v to +5v swing. "ENV" mode outputs a 0-5v signal, and "CYCLE" a +/-5v waveform (10v peak-to-peak). The gate input features a internal comparator that ensures gate signals are always converted to a 0-5v signal before reaching the slew processor, to ensure that sub-5v gate signals still generate a 0-5v output when the module is used as an AR envelope generator.

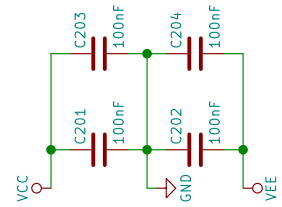
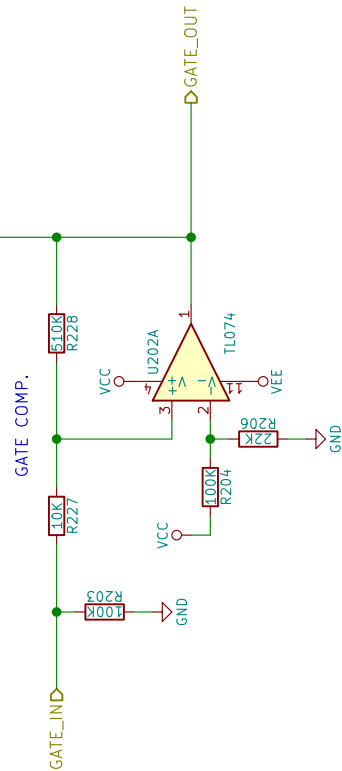
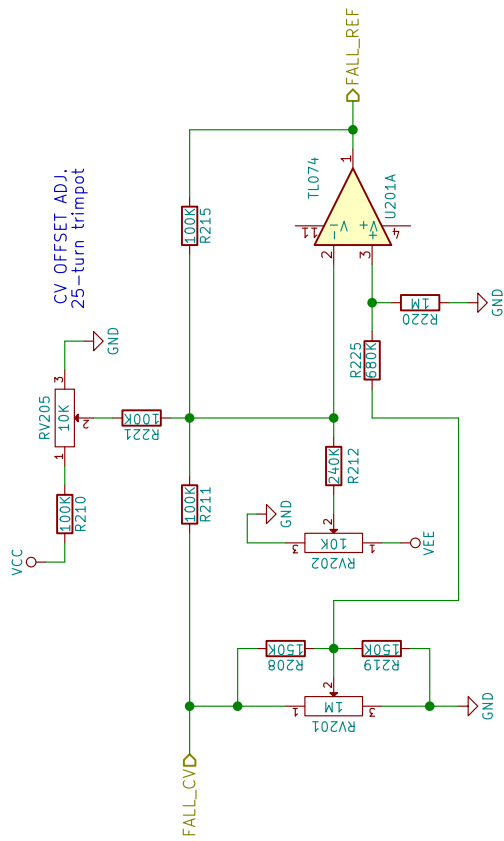
## CIRCUIT OVERVIEW

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

As mentioned in the introduction, the heart of the Model 2231 is the voltage controlled slew processor / integrator that limits the rate of change of incoming signals. A handful of surrounding circuits implement the various functions of the module, and the entire unit can be broken down into the following:

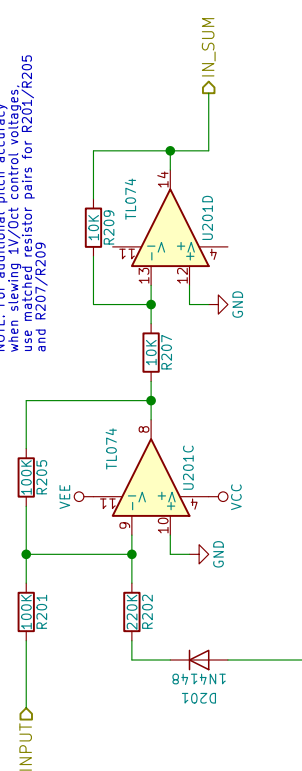
- 1. Signal inputs** - This consists of a comparator for the "gate" input, and a summing amplifier / buffer that mixes the "input" signal and the output of the comparator before feeding it to the slew processor.
- 2. CV processors** - These are a pair of attenuverters which scale and offset the rise and fall CVs to produce the correct voltage range needed for the slew processor.
- 3. Voltage controlled integrator** - The heart of the module, this uses the converted CV voltages to control the currents flowing into and out of an integrator.
- 4. Rise/fall comparator** - This compares the input signal with the current voltage in the integrator and generates either a high or low voltage to feed into the integrator, essentially deciding whether the integrator needs to "rise" or "fall" to reach the target voltage. In "CYCLE" mode this is fed back into itself to form a Schmitt trigger.
- 5. Envelope flip-flop** -A simple flip-flop circuit that enables the envelope cycle to auto-complete even if the input gate goes low.
- 6. Output / LED buffers** - These buffer the output jack and control the bicolour "level" LED to provide visual feedback of the current output.





INPUT + GATE SUM

NOTE: For additional pitch accuracy when slewing 1V/oct control voltages, use matched resistor pairs for R201/R205 and R207/R209



## SIGNAL / GATE INPUTS

The input circuits for the 2231 "signal" and "gate" inputs are relatively simple. The "gate" input is fed straight into a comparator with a threshold voltage of  $\sim 2.5\text{V}$ , this allows for predictable 0-5V output voltages when using the module as an AR envelope generator in "SLEW" mode. Without this circuit, the maximum envelope voltage would be the input gate voltage, which is not guaranteed to be 5V (especially with diode-coupled gate outputs).

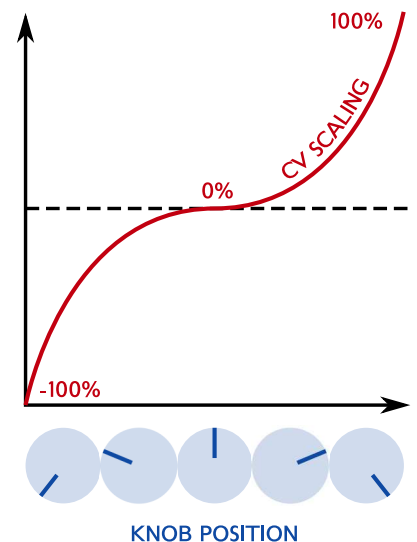
Both the output of this comparator and the "input" signal are summed together by the inverting summing amp U201C. The gate comparator summing resistor is a considerably higher value in order to limit the rail-to-rail output of the comparator to 0-5V after the negative portion has been clipped by D201. The output of this amp is then fed into another inverting amplifier in order to flip it back to the original polarity.

## CV INPUT ATTENUVERTERS

The inputs for the rise and fall CVs are fed into a pair of attenuverters that allow the signals to be multiplied by a factor between -1 (fully inverted) to +1 (original signal), with the centre position of the attenuverter control being zero (no signal). These amplifiers also sum the values of the respective "RISE" and "FALL" control knobs together with the CVs, as well as the values of the CV offset adjustment trimmers. These trimmers allow the slowest rise and fall times to be set, and are necessary because of natural variations in the  $V_{BE}$  values of the transistors in the slew processor, which affect the relationship between CV voltage and slope time.

It's worth looking briefly into the operation of these attenuverter circuits, which work by moving the opamp's non-inverting input between ground and the input signal. When the potentiometer's wiper is fully over to the grounded side, the input is also grounded and the circuit behaves like a traditional inverting amplifier. When the wiper is at the other extent, the non-inverting input is following the input signal, which subsequently appears at the output. R226/R222 are necessary to get the correct roughly-unity gain in this mode, as the amplifier's gain on the non-inverting input is greater than 1 in this configuration.

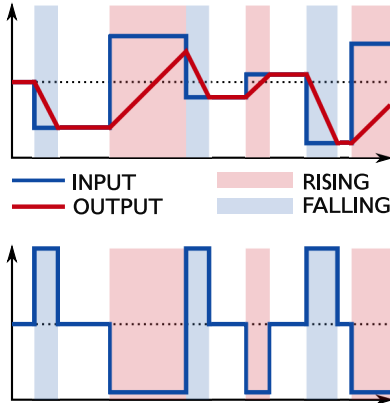
The lower-value voltage dividers across the potentiometer (R208/R219 and R224/R223) change the scaling curve of the control, causing the sensitivity to be low in the centre position and grow increasingly more sensitive as the knob is swept toward either of the two outer positions. This works by taking advantage of the changing resistance in the two sides of the potentiometer relative to the static resistors, which dominate in the centre position owing to their lower value.



*Demonstration of the attenuverters' operation. The non-linear response created by the additional voltage dividers makes the control more usable across all the modes of operation.*

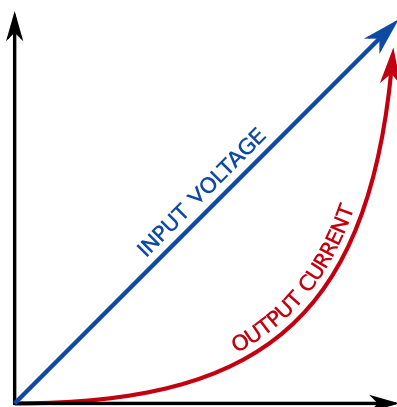
*In ENV mode for example, small CV adjustments make huge differences to the attack/decay times, whereas when using the 2231 as a lowpass filter in SLEW mode, much larger CV swings are required to sweep a large enough chunk of the audio range.*

## SLEW PROCESSOR / OUTPUT



Basic operation of the slew processor. The top diagram shows the relationship of the input to output with a fall rate approximately twice as fast as the rise rate. The bottom graph shows the output of the comparator as it switches between rising and falling mode.

(Note that in reality the comparator will usually go into high-frequency oscillation when the integrator reaches the target voltage, rather than settling neatly at 0v as shown here).



Voltage-current response of the exponentiator circuits that feed current into the main integrator. This ensures that the control sensitivity remains usable across the complete range of rise/fall times.

The slew processor at the heart of the 2231 is a combination of a voltage controlled integrator and a comparator that drives it to either rise or fall depending on whether the current integrator voltage is higher or lower than the target. The integrator itself has two parts - a pair of voltage-controlled current sources that each handle one current direction (either into or out of the integrator), and a standard opamp integrator consisting of an opamp (U301B) with a capacitor in its feedback loop.

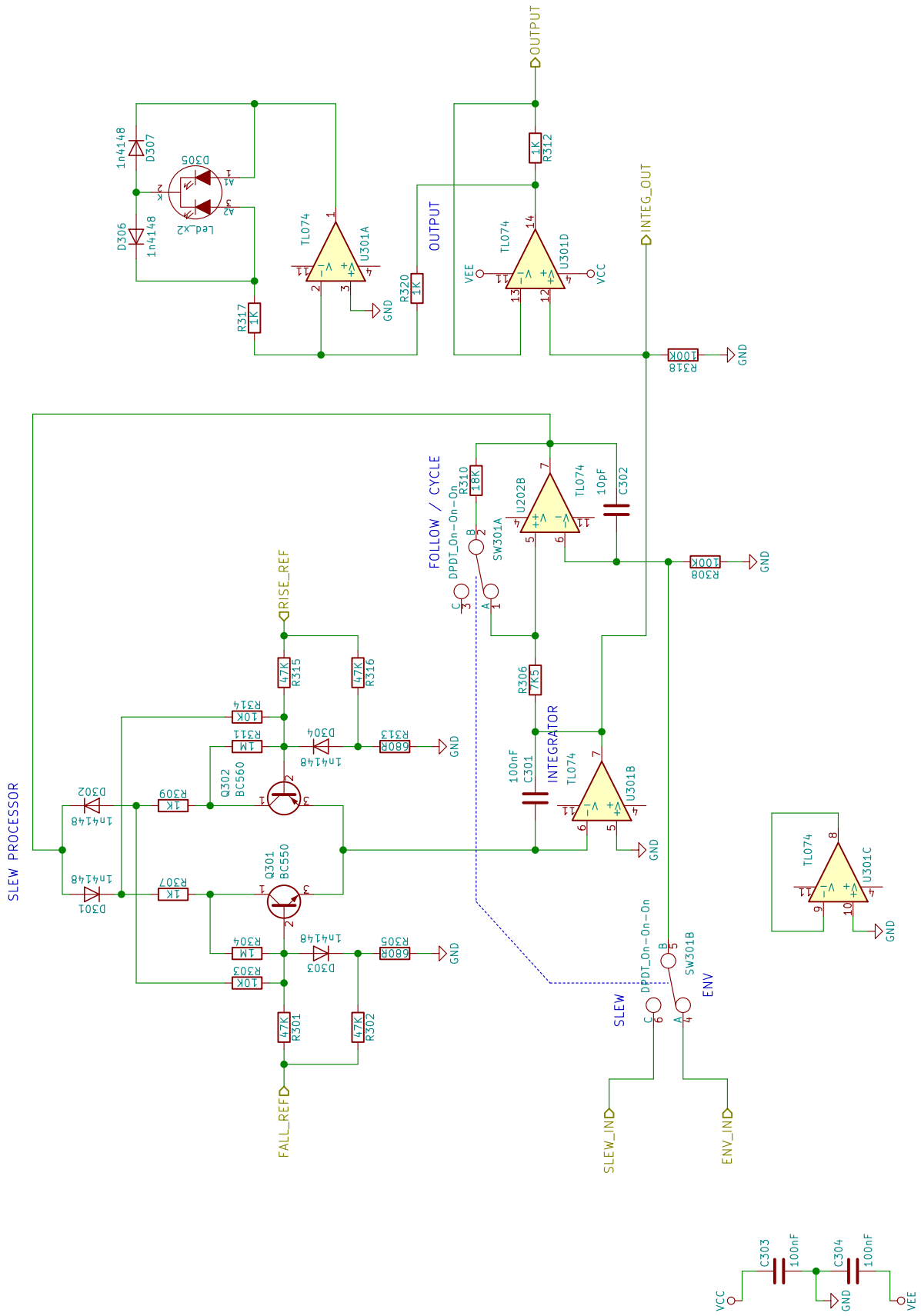
The current sources are simple discrete designs that use a single transistor to both perform the linear-exponential conversion needed to make the CVs responsive over a wide range (from audio rates to near-DC), and to supply the actual currents to the integrator. The voltages from the CV input attenuverters are dropped down by a voltage divider (the 47K and 680R resistors) into the exponential region of the transistors' operation, while a diode is used to counteract the temperature drift of the transistors'  $V_{BE}$  by providing an opposing drift with temperature. This temperature compensation scheme is very basic and not at all precise, but entirely adequate for the intended roles of the module. Crossfeed resistors R303 and R314 apply a bit of reverse bias to the transistors when their opposite number is active, preventing both transistors from passing current simultaneously and creating an undesirable current path between them.

The output of the integrator is fed into a comparator, U202B, that takes as its threshold the "target" voltage. If the current integrator voltage is higher than the target, then the output is driven high (as opamp integrators are inverting), and if it lower then the output goes low. This output provides the source current for the voltage controlled current sources that feed the integrator. The comparator's threshold is taken from either the input signal amplifier (in "SLEW" and "CYCLE" modes) or the envelope flip-flop (in "ENV" mode). The reason that the input signal is still connected in "CYCLE" mode is down to the way that three-position toggle switches work - they are actually a pair of two-position switches that switch between three arrangements (AA, AB, BB). In normal use the input jack would not be connected when the module is being used in "CYCLE" mode.

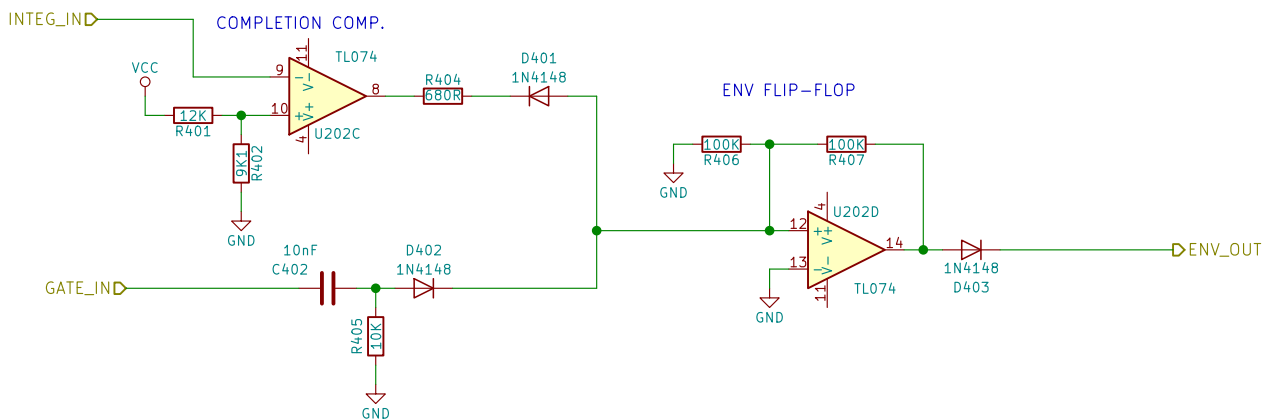
In "CYCLE" mode the comparator has a positive feedback path switched in (via SW301A on the schematic) which converts its operation to that of a Schmitt trigger. This arrangement has hysteresis, meaning that the comparator's threshold actually changes depending on whether the output is high or low. This causes the comparator to perpetually "chase its own tail" as the target voltage automatically switches between +/- 5v each time the existing target voltage is reached. Hence in this mode the circuit behaves like a free-running oscillator where the pitch and waveshape are dependent on the rise and fall rates.

The output of the integrator is already in the correct output voltage range and can be simply buffered through U301D directly to the output jack. The buffered

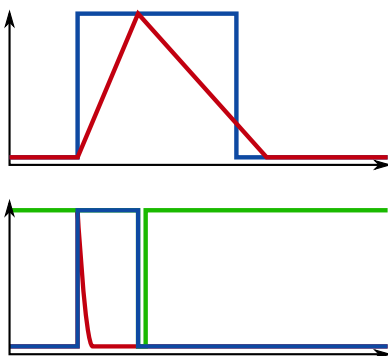




output also goes to the bicolour LED indicator to provide a visual feedback of the current output voltage. The reason for positioning the output LED in the feedback loop of an opamp is that this configuration removes the effect of the LED's threshold voltage / diode drop - the opamp will automatically raise the voltage until the desired current flows through the LED junction - meaning that we get a nice linear change in brightness all the way from 0v to +/-10v, with no "dead zone" in the centre. **Note that D306 and D307 are not required when using a two-pin bicolour LED, and are only needed for three-pin (shared-cathode) LEDs.**



## ENV E N V E L O P E F L I P - F L O P



Operation of the ENV flip-flop. Top diagram shows the gate input and module output, the lower diagram shows the flip-flop output (blue), the gate positive edge trigger pulse (red) and the completion comparator output (green)

The "ENV" mode of the 2231 requires an additional bit of logic in order to implement the desired behaviour of auto-completing a rise/fall cycle on each gate trigger. This takes the form of a simple flip-flop and a comparator - when a gate signal is received (and converted to a positive-edge pulse by the RC network of C402, R405, and D402), the flip-flop is set "high" and outputs a target voltage for the slew processor of essentially the full positive rail voltage (~12v). As the slew integrator's voltage rises above 5v (set by the voltage divider R401/R402), the completion comparator changes state and resets the flip-flop to "low",

So far, this circuit has operated essentially the same way as the "CYCLE" circuit's schmitt trigger - however in the case of the "ENV" circuit a key difference is the presence of the diode D403 on the flip-flop's output. Because this prevents the flip-flop from pulling down the target voltage, the voltage on the slew processor's comparator is instead pulled to 0v by the 1M resistor (R308) on its negative input. Hence the slew processor slews down to 0v and then stays there, until the next gate trigger pulse.

# BILL OF MATERIALS

Resistors		QTY
10R	2	R101, R102
680R	3	R305, R313, R404
1K	5	R307, R309, R312, R317, R320,
7K5	1	R306
9K1	1	R402
10K	6	R207*, R209*, R227, 303, R314, R405 * Match if tight scaling accuracy is desired
12K	1	R401
18K	1	R310
22K	1	R206
47K	4	R301, R302, R315, R316
100K	17	R201*, R203, R204, R205*, R210, R211, R213, R215, R216, R217, R218, R221, R308, R318, R406, R407 * Match if tight scaling accuracy is desired
150K	4	R208, R219, R223, R224
240K	2	R212, R214
220K	1	R202
510K	1	R228
680K	2	R225, R226
1M	4	R220, R222, R304, R311

Potentiometer		QTY
10K	2	RV202, RV204
10K 25-Turn	2	RV205, RV206
1M	2	RV201, RV203

Capacitors		QTY
10pF	1	C302
10nF	1	C402
100nF	7	C201, C202, C203, C204, C301, C303, C304
100uF	2	C101, C102

Semiconductors		QTY
1N4148	10	D201, D301, D302, D303, D304, D306, D307, D401, D402, D403
Bicolour LED	1	D305
BC550	1	Q301
BC560	1	Q302

Integrated Circuits		QTY
TL074	3	U201, U202, U301

Switches		QTY
DPDT On-On-On	1	SW301

Connectors		QTY
10-pin IDC Header	1	P101
10-pin 2.54mm Pin Header	2	
10-pin 2.54mm Female Pin Header	2	
Banana Socket <b>Blue</b>	3	
Banana Socket <b>Red</b>	1	
Banana Socket <b>White</b>	1	

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

## CHOOSING COMPONENTS

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Like all Slightly Nasty modules, the 2231 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.

The DPDT On-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 bi-colour red/green LED and its associated panel lens is the only "unusual" part that might not be available from all vendors, though there are a number of options available for the LED itself that will work with the 2231. Most modern two- or three-pin red/green LEDs should be suitable, though the value of R317 may need to be made bigger or smaller to get the brightness to the desired level.

The lens is a low-profile 3mm Fresnel type, I use the **VCC SMB-200-CTP** (**Mouser: 593-2000C**, **DigiKey: SMB\_200\_CTP-ND**), though if you can find a part with matching dimensions that should be suitable as well.

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 transistors it's important to hold the iron long enough to get a solid joint that extends down into the plated hole, but not so long that you risk thermal damage to the transistor junction. With a properly heated iron, a few seconds on each should be all that's required.

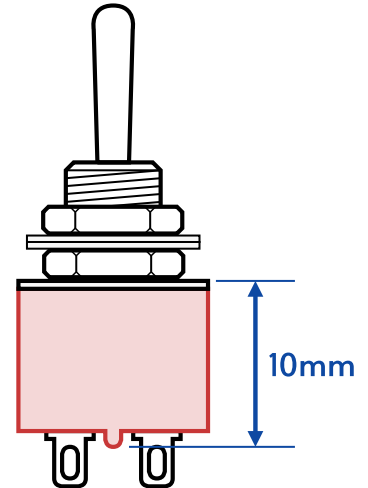
When soldering rectangular capacitors, I like to solder one leg on each, then hold the board in one hand while applying a very light pressure on top of the capacitor with a free finger, using the other hand to reheat the solder joint until the capacitor slides down tight against the PCB's surface. Continue 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.

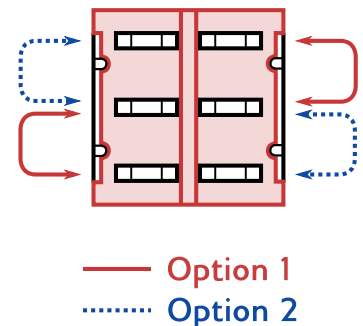
**The DPDT mode switch in the 2231 is probably the component that requires the most attention during construction.** As mentioned in the "Component Selection" guide on the previous page, the switch itself must first be checked for correct height when mounted to the board. Soldering the switch into place 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.

Because the switching order of the pins is different between various On-On-On switches, three wire jumpers need to be added to "configure" the board for the particular switch you are using - this really just flips the top and bottom pads of the switch footprint. Use the diagram on the right to ascertain which of the two sets of jumpers you need to solder for your particular switch.

Soldering the LED into place is also something best done with the face panel temporarily mounted, and the LED lens inserted into its hole. With a finger holding the lens down against the panel, push the LED into the other end (either using tweezers or just by pushing the legs from the other side of the PCB) until



*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.*



*To determine which set of jumpers need to be fitted, set the switch toggle to the centre position and check the continuity across the centre and outer pins on each side. The diagram above shows which pins should be shorted for each of the two options.*

---

the LED clicks into place in the base of the lens. You can then solder it in place and trim the excess as usual.

(If you are unsure of the polarity of your LED, it's probably worth soldering it temporarily in place at the end of the build and testing the circuit in a slow "CYCLE" mode, using an oscilloscope to check that the LED is indicating green when the output voltage is positive.)

The pin headers that interconnect the two boards are another component that needs a bit of additional care when assembling to ensure correct alignment. 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.

#### A NOTE ON POWER FILTERING

It's common practice among some builders to replace the 10 ohm power filter resistors with ferrite beads, in the belief that this will prevent power rail fluctuations under varying current loads while still providing the filtering action desired. **This is not recommended.** Ferrite beads do not even begin to show reactivity until somewhere up around the 1MHz mark, an order of magnitude beyond the audio range. Within the audio band (and for a long way beyond it) they are electrically identical to a wire jumper.

## PHYSICAL ASSEMBLY

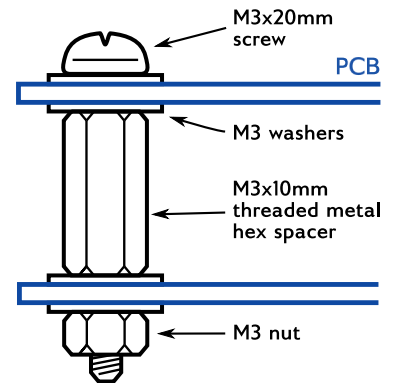
Assembling the finished PCBs and front panel is very simple. Begin by fitting the M3 hardware to the panel-side PCB, screwing the hex spacer tight to hold it all together. Once all four screws are in place, start fitting the banana sockets into their respective holes on the front panel - making sure 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.

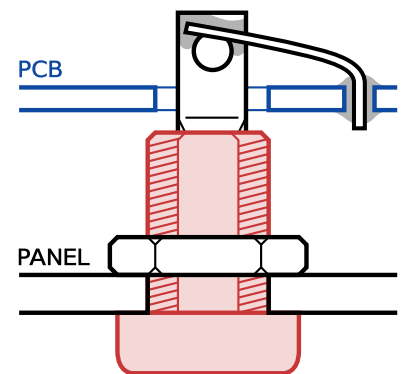
Now you'll need to connect the banana sockets to the front PCB using either some offcut component leads, or tinned copper wire. The simplest way is to solder the straight pieces of wire vertically into the pad on the PCB, then bend them over to meet the banana socket and solder that end to the flat side 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.



*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.*

## CALIBRATION

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The 2231 does not require any critical calibration in order to function, however owing to the variation in the characteristics of the transistors used in the slew processor, there are two trimpots that allow the lowest slew rate to be adjusted. This allows you to remove any "dead zone" at the slower speeds (where the slew rate drops to zero), or correct a maximum slew rate that is still too fast.

There is no real "correct" setting for these trimmers, just set the rise or fall time to its maximum setting in "CYCLE" mode, and then adjust the trimmer to get a rate that feels right to you, and matches the other controls.

Personally, I set these by putting my oscilloscope into "roll" mode and then adjusting the trimmer until I just start to see a discernable motion of the trace in the right direction, then use the time it takes for the trace to jump down one line of pixels on the screen as the reference to match it to the other control. The setting of these trimmers doesn't need to be hugely precise, just as long as both the rise and fall knobs are all operating across more or less the same range.

### 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.



# CONTROLS

**RISE/FALL RATE CONTROLS**  
Sets the initial RISE and FALL rates.  
Left is faster, right is slower.

**CV ATTENUVERTERS**  
Allow the RISE and FALL CVs to be scaled between -1 and 1.

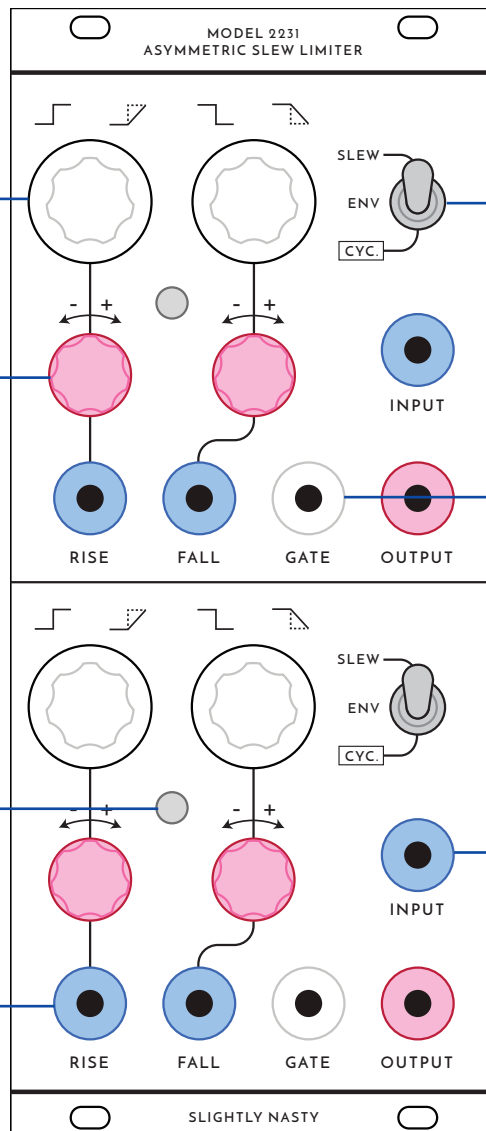
**MODE SWITCH**  
Selects between the three operating modes of the 2231.

**GATE INPUT**  
Logic input with a threshold of 2.5V, triggers the ENV mode and provides a clean 0-5V input when using the SLEW mode for AR envelopes

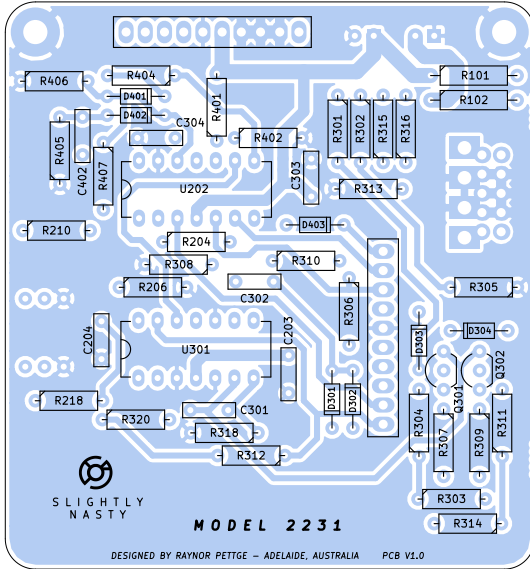
**LEVEL LED**  
Provides visual feedback of the current output voltage. Green is positive, red is negative.

**RISE/FALL CV INPUTS**  
Allow voltage control of the RISE and FALL rates.

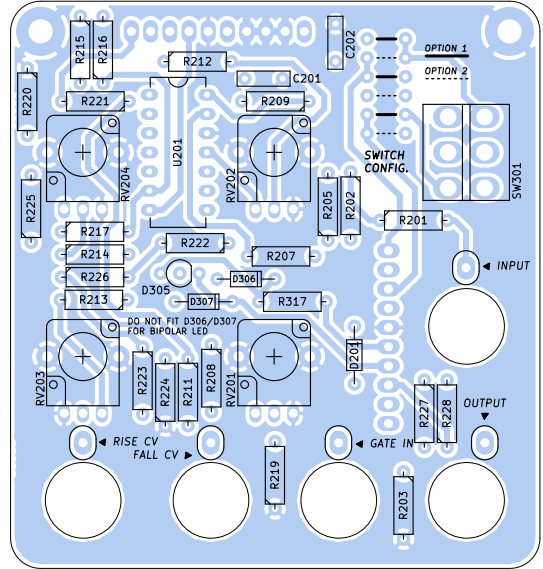
**INPUT JACK**  
Signal input for SLEW mode.



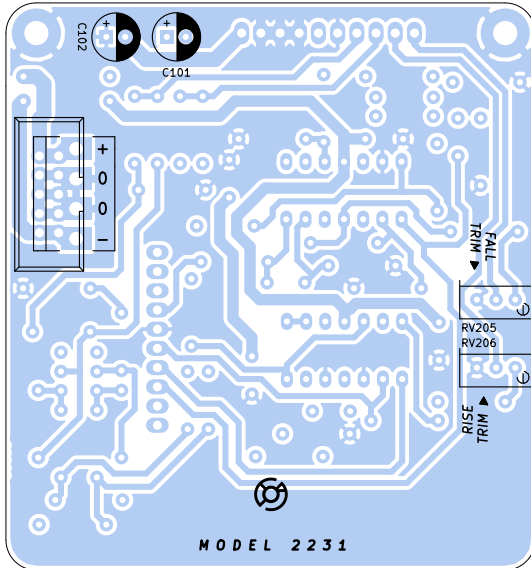
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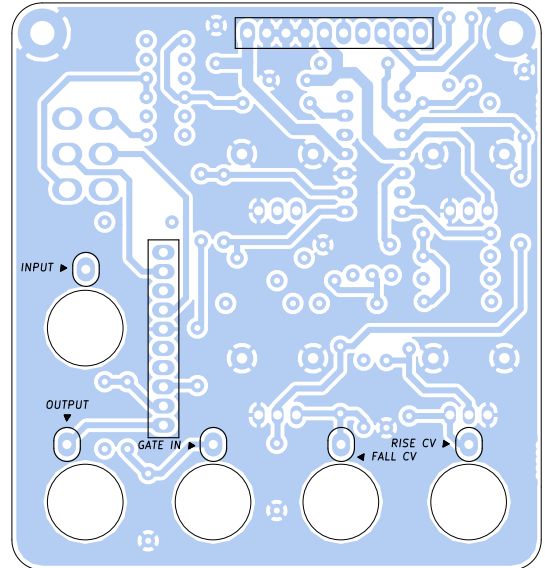
LOWER BOARD - TOP



UPPER BOARD - TOP



LOWER BOARD - BOTTOM



UPPER BOARD - BOTTOM



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