Wavefolder

Kassutronics

Board revision 1.0, build documentation revision A November 29, 2021

Description

Wavefolders are one of the key elements in so-called *West-coast* synthesis techniques. When fed with a relatively pure waveshape such as a sine or triangle, the wavefolder adds harmonics to the sound by *folding over* the waves in some way. Thus, a wavefolder is essentially an extremely nonlinear amplifier, where the folds in the transfer function strongly distort the sound.

The character or timbre of this distortion depends however on the details of the transfer function. In this module, the wavefolding core is based on a series of simple transistor circuits, that create rounded-off folds for a smooth sound, somewhat (but not quite) like higher-order sine waves. The amount of wavefolding is adjusted by the large **Fold** control. Starting with a nearly undistorted sound at the counter-clockwise position, turning up the Fold control adds folds one-by-one, up to the full 7 folds. Turning even further, the wavefolder leaves it's normal operating regime and starts to internally saturate and eventually clip. At this point it is perhaps not a proper wavefolder anymore, but that doesn't mean it doesn't sound good!

The **Odd / Even** control adjusts the transfer function to create predominantly odd or even harmonics, which each have a different character, or at in-between settings creates a fuller sound with all harmonics. The wavefolder core is followed by an overdrive circuit. Turning up the **Drive** contol adds warm saturation to the sound, and at higher settings starts creating a sharper edge, giving the wavefolder some punch. At extreme settings, the overdrive turns the once gentle sinusoidal folds into nearly ear-splitting square waves. The final step in the signal chain is an integrated VCA, with the output amplitude controlled by the **Level** control.

As with all synthesis techniques, wavefolders become musically interesting when introducing *dynamics*, i.e. changes to the timbre over time. To this end, the wavefolder has CV inputs for the fold amount and for the VCA, with an attenuator control for each. Adding just a little bit of **Fold CV** creates pleasent dynamics and satisfying bass sounds, while turning up the modulation depth releases all the chaos this module has to offer. The **Level** control does just what it says - control the VCA level (or output level if no signal is connected to the VCA jack) - but having the it closeby will come in handy to keep the wide range of timbres balanced in the mix.

For those who want even more CV options, at the cost of a little extra panel space, three expansion points are provided. Two allow for extra inputs for the Fold and Level CV, respectively, and the third adds voltage control over the Odd / Even knob. Wiring instructions for these are given at the end of the documentation.

Features

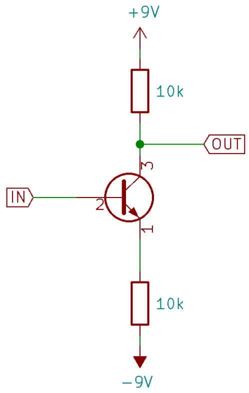
- Voltage-controlled wavefolder
- Symmetry and overdrive controls
- Rich range of timbres
- Integrated VCA
- Expansion points for extra CV inputs
- 8hp Eurorack format
- All through-hole construction

Power supply requirements

Supply voltage	Current
+12 V	35 mA
-12 V	30 mA

Circuit description

At the heart of the wavefolder is the following little circuit, which uses a single transistor to make a full wave rectifier.

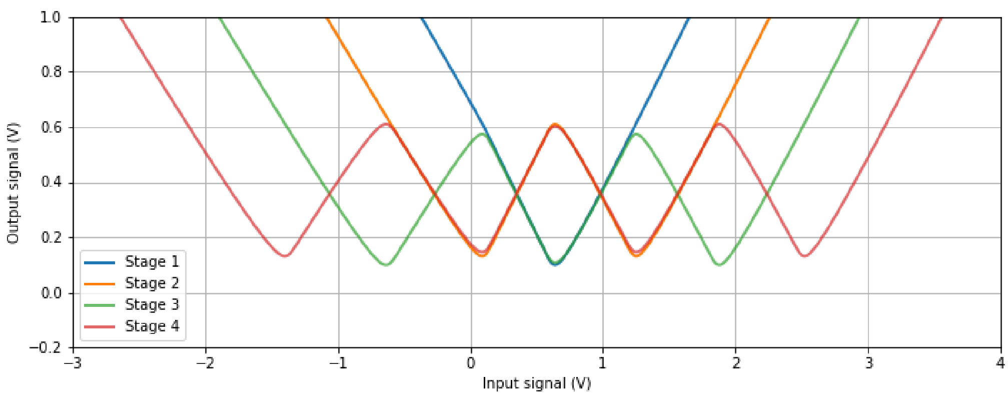


This circuit was originally used by Robert Moog as a saw-to-triangle converter. It works by cleverly using two regimes of amplification of the transistor. For negative input voltages, the transistor forms a common emitter amplifier, with a gain of −1 set by the ratio of the two resistors. Hence, for a negative input voltage the output is positive.

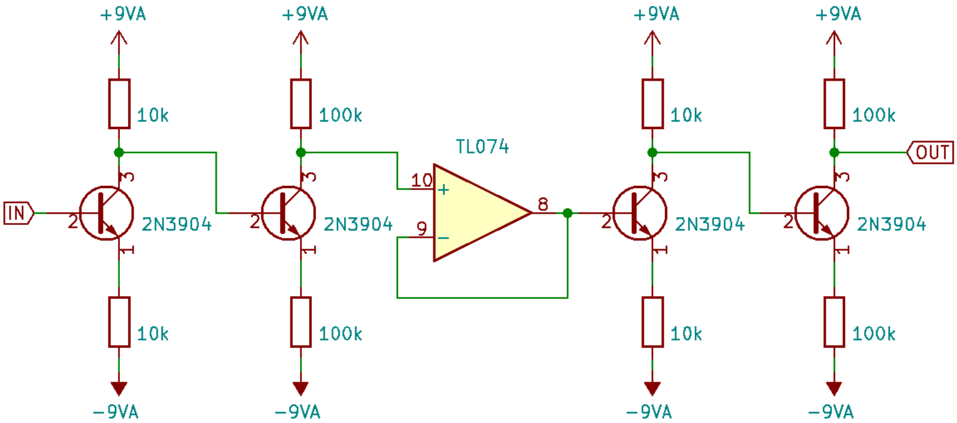
When the input is positive (or, more precisely, above one diode drop or about 0.7 V), the base-emitter junction of the transistor becomes forward biased and it functions as an emitter follower. Hence, in this case the output voltage is always one diode drop below the input voltage, and the gain is +1.

The transition between these two regimes is not abrubt, but rather smooth giving a rounded off transfer function. For this reason the circuit is not often used anymore as saw-to-triangle converter, but for the wavefolder the smooth transition ensures a soft sound.

The full core of the wavefolder contains four of these full wave rectifiers in series. The first rectifier creates a single folding point at an input of +0.7 V as described above, but it's output passes +0.7V twice. Hence, the next stage adds two folding points, when the original input signal is +1.4 and about 0 V. Similarly, each following stage adds two more folding points creating a total of 7 folds with 4 stages. The crucial part here is the 0.7V voltage drop of each stage in emitter-follower mode, that offsets the folds from each other. The following figure shows the output voltage after each stage. The following figure shows the output voltage of each stage.



In all of its simplicity, the single transistor rectifier also has some limitations. The first is relatively low current gain, which is different for positive and negative inputs. Hence, the stages cannot be simply cascaded indefinitely without some extra buffering in between. As shown in the full four-stage schematic below, this is addressed in two ways. Two stages are cascaded directly, but with a factor 10 different resistor values, reducing the output loading effect of the first stage significantly. Then an opamp buffer is used, followed by two more cascaded stages.



Another limitation in cascading the stages is that the folds of earlier stages are rounded off further by later stages. For four stages as shown this effect is negligible, but for much longer chains this changes the behaviour significantly.

Finally, the transfer function of the wavefolder depends on the balance between the resistor values, and more importantly the power supplies. The latter means that the calibration of the module would depends on the supply votlages, and further that any noise on the power supply propagates to the output. Both of these issues are addressed by ± 9 V regulators in the module.

It's worth noting that the sound character of any wavefolder depends on how the input signal is biased, i.e. what DC offset it has. If the input signal is centered around the first fold at $+0.7$ V, the transfer function is symmetric between positive and negative excursions of the input. Symmetric distortion only creates even harmonics, i.e. the double, quadruple, etc frequency of the input. On the other hand, when biased half-way between two fold points, the transfer function is antisymmetric, creating only odd harmonics like third, fifth, etc overtone. The odd/even control allows the users to choose between these cases, as well as any bias in between which creates a mix of all odd and even harmonics. Since the symmetry is defined by only an offset voltage, adding CV control here is trivial and while there was no suitable space on the panel, it is offered as expansion option. To simplify biasing, both the input and output of the wavefolder core are AC coupled.

To have votlage control over the number of folds, the input signal amplitude needs to be modulated, which is achieved with the fairly standard OTA amplifier U1A. The amplifier itself is fairly linear, using the linearizing diodes technique of the LM13700.

The output of the wavefolder core sounds nice and round, but without further processing can be a bit boring. To give it a bit more edge, and broaden the range of possibilities offered by the wavefolder, the output is fed to the second half of the LM13700, U1B, in the VCA stage. Here, the linearizing diodes are not used, giving access to the smooth hyperbolic tangent transfer function of the differential transistor pair in the OTA. By adjusting the drive knob, this goes from fairly linear, via mild distortion, to hard overdrive producing rounded-off square waves at the output.

Since the signal is going through U1B already, the VCA function comes basically for free. The VCA input is normaled such that without CV input, the level control adjusts the VCA gain directly, and with cable connected it attenuates the CV as needed.

Build instructions

When sourcing parts, pay special attention to the dimensions specified in the Bill of Materials. In particular C1 and C2 should be low profile, such that they fit between the PCB and panel.

The component values on the silkscreen and schematic agree, so you can follow either. Note that resistors have their designators (Rxx) printed on the backside of the PBC, and the value on the front side.

The **headers J6, J7 and J8 are optional**, their silkscreen labels are on the backside of the pcb. Beware not to solder other components to these holes. For instructions on their use, see page 13

Resistor matching

For best results, the following resistors should be matched pairwise to about 0.2% accuracy: R22 with R23; R24 with R25; R26 with R27; and R28 with R29. This can be done by simply measuring several resistors, and selecting for each pair two that are close to each other. For 10k resistors they should be at most 0.02k different, and for 100k resistors they should be at most 0.2k. The module will also work with standard 1% resistors, but the transfer function may have a few extra smaller kinks.

Before powerup

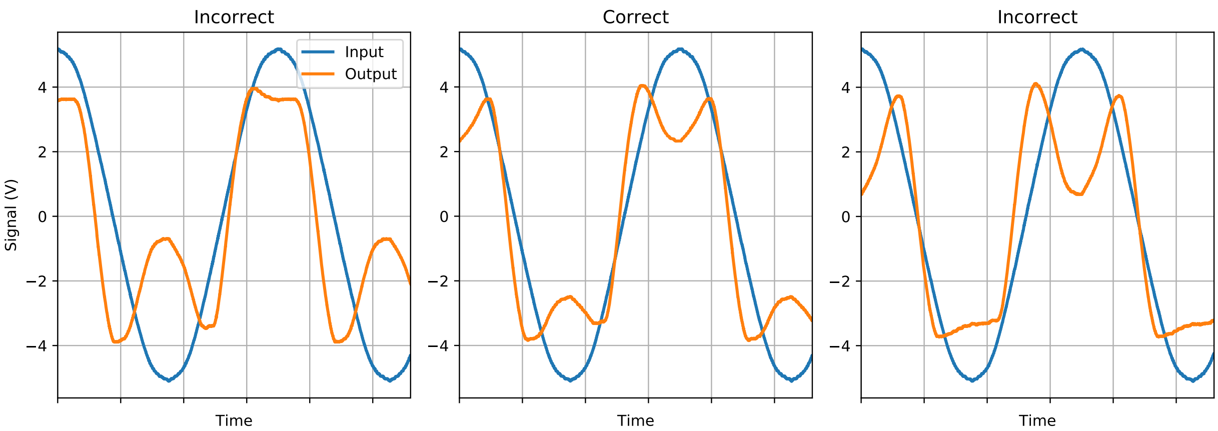
Before applying power for the first time, follow these steps.

1. Inspect the boards for shorts or bad joints.
2. Measure the resistance between the +12V and GND and between the GND and -12V power connections. The values will change while measuring due to the large capacitors, but should increase to at least the kΩ range after several seconds.

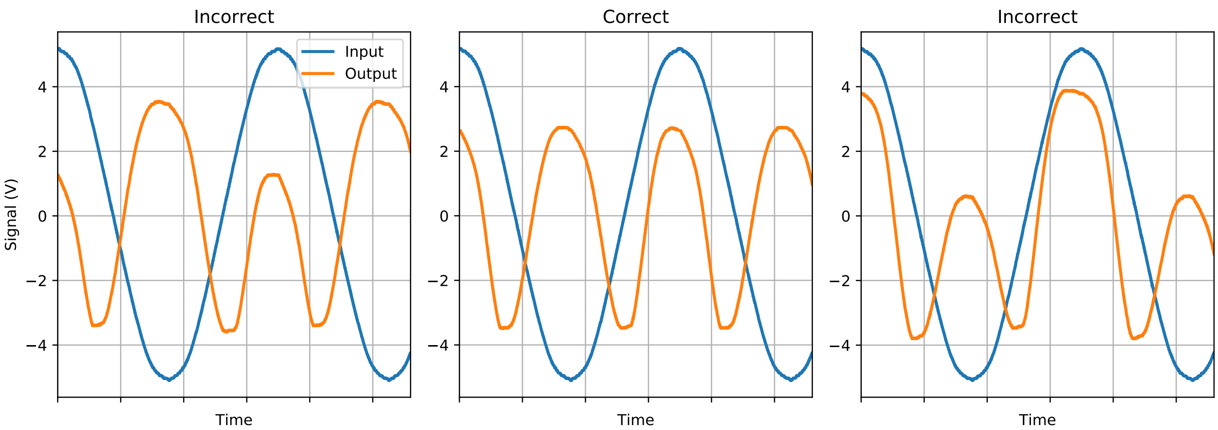
Calibration

To calibrate the Wavefolder, you will need a VCO with sine or triangle output, and an oscilloscope of some sort. If you don't have a separate oscilloscope, you can connect the output of the wavefolder to your sound card (in whatever way you normally connect signals from your modular) and use a free soundcard oscilloscope program, or the oscilloscope view that may be built into your DAW.

To start, connect the sine or triangle wave (ideally around 10Vpp amplitude) to the wavefolder input, and the output to your oscilloscope. Turn the controls as follows: Drive to minimum, Level to maximum, and symmetry to Odd. Then adjust the Fold control until you see only about one or two wave folds in the output signal. It should look something like one of the three plots below. You may need to adjust the **Initial fold trim (RV5)** a few turns either way to get this waveform.

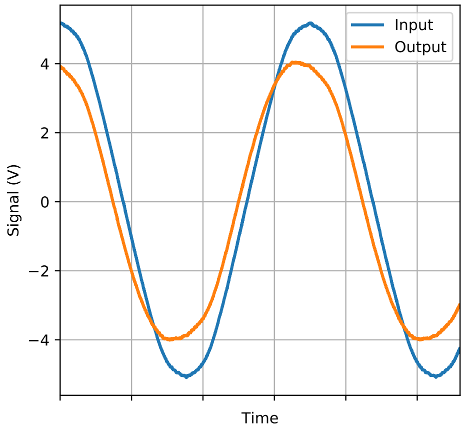


Now, start adjusting **Odd trim (RV8)**. This will move the folds up and down. Adjust the trimmer until there is an equal amount of folding on both the top and bottom of the wavefolder, like in the middle panel above. It may help to adjust the Fold control a bit to get a better view of the signal.



Next, set the symmetry control to Even, and start adjusting **Even trim (RV7)**. The figure above shows what the signal should look like, when adjusted correctly there should be double the number of peaks from the input signal, with both of them equal amplitude. This is shown in the middle panel above.

Finally, set the symmetry back to Odd, and turn the Fold all the way counter-clockwise. Now adjust the **Initial fold trim (RV5)** until the output is a clean sine wave, as large as possible without distorting, as shown in the figure below.

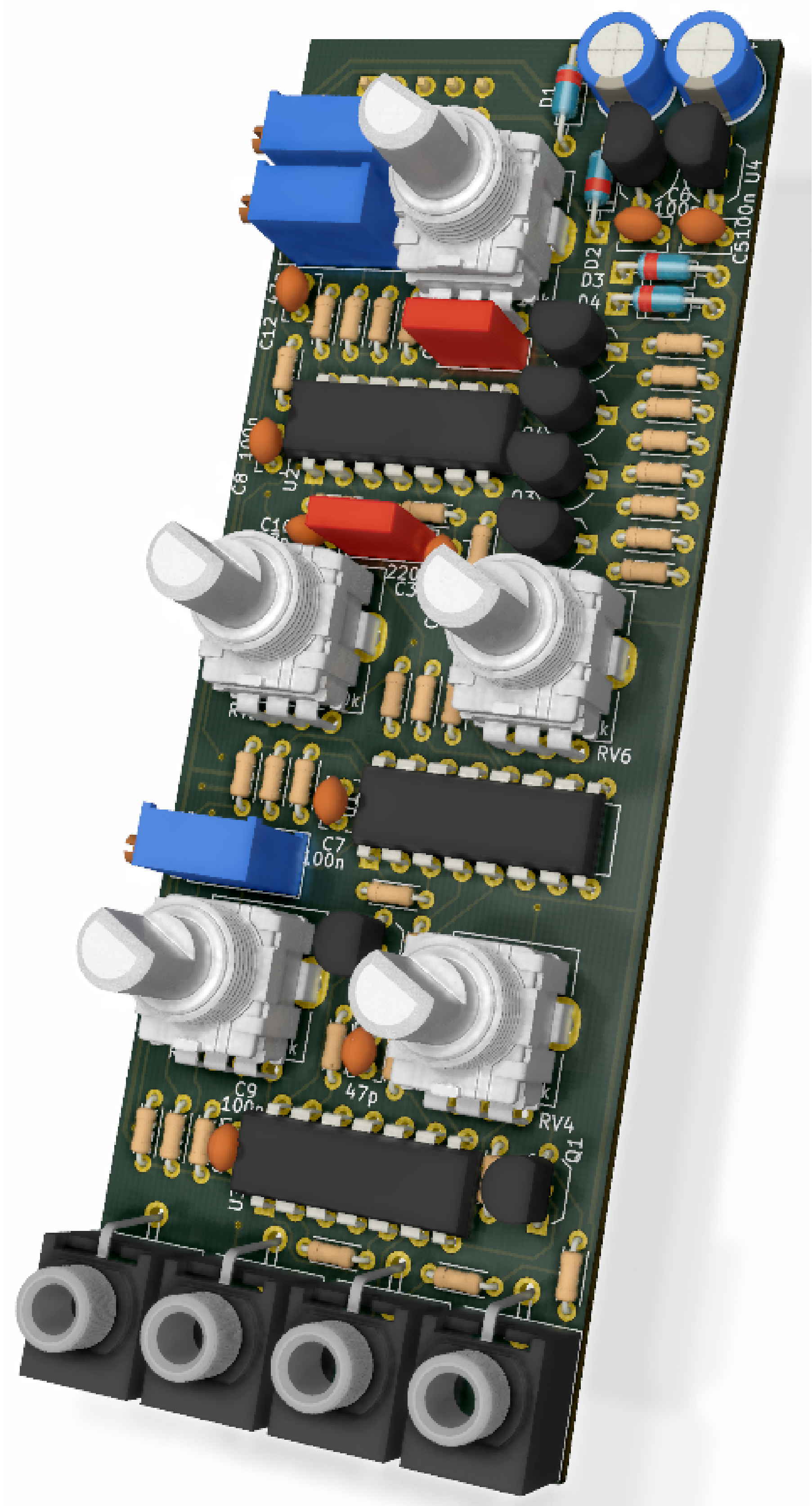


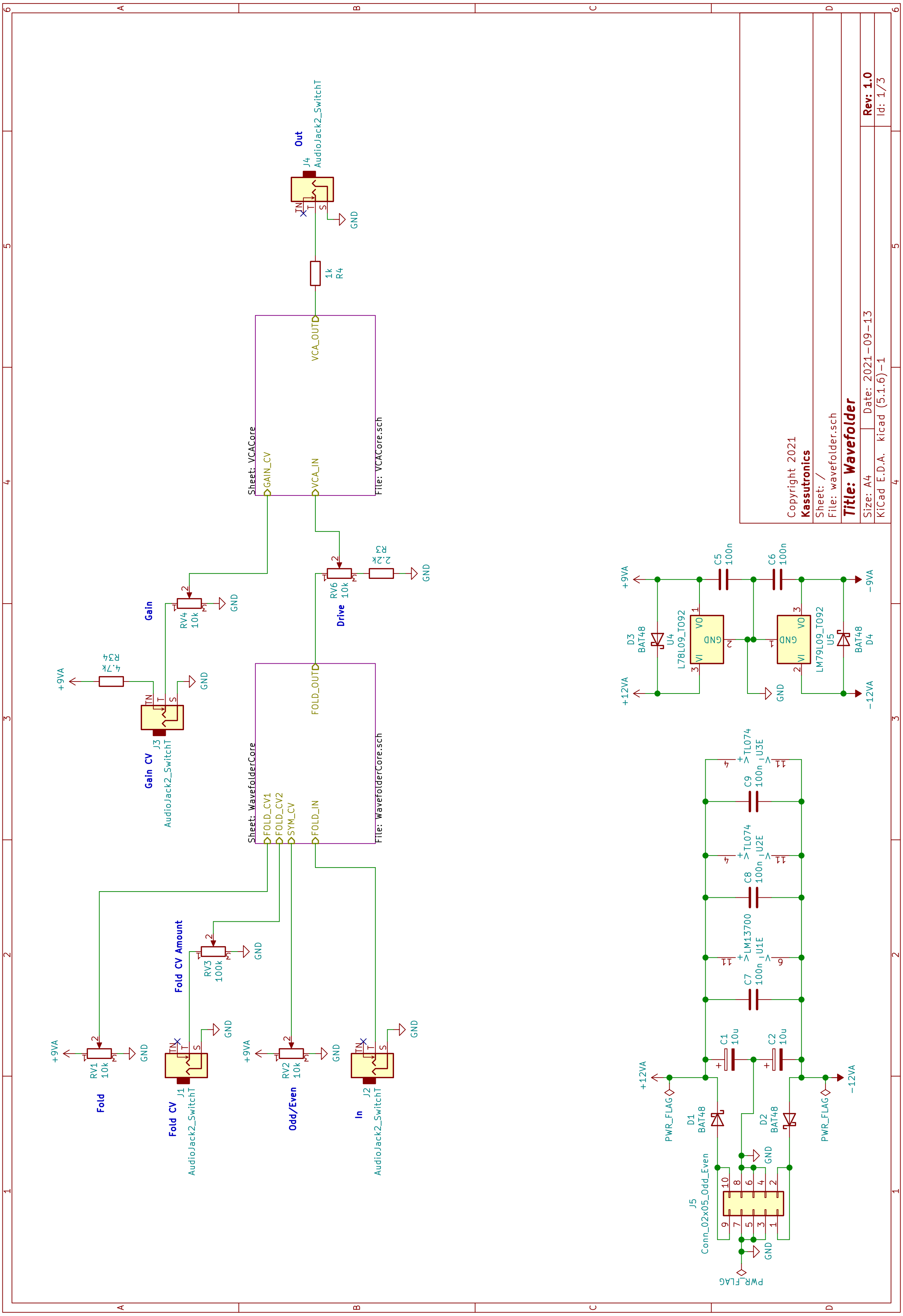
That’s it, your Wavefolder is now calibrated and ready for use!

Bill of materials

Qty	Designator	Value	Note
1	J3	2x5	Male pin header 2.54mm pitch
4	J9, J10, J11, J12	1x6	Male pin header 2.54mm pitch
2	C1, C2	10u	Diameter 6.3mm, pitch 2.5mm, max height 9mm (Nichicon UST1H100MDD)
1	C3	220n	Polyester, 5mm pitch
1	C4	22n	Polyester, 5mm pitch
5	C5, C6, C7, C8, C9	100n	Ceramic, 2.5mm pitch
4	C10, C11, C12, C13	47p	Ceramic, 2.5mm pitch
4	D1, D2, D3, D4	BAT48	Any Schottky diode rated $V_F \geq 100$ mA (e.g. 1N5817/8/9)
4	J1, J2, J3, J4	Thonkiconn	Thonkiconn (PJ398SM) 3.5mm audio jack
1	J5	2x5	Male pin header 2.54mm pitch, boxed or unboxed
3	J6, J7, J8		
2	Q1, Q6	2N3906	
4	Q2, Q3, Q4, Q5	2N3904	
4	R2, R6, R7, R10	470	All resistors 1% metal film
2	R4, R18	1k	
1	R3	2.2k	
3	R5, R31, R34	4.7k	
7	R1, R14, R16, R22, R23, R26, R27	10k	
1	R8	15k	
1	R9	22k	
1	R17	47k	
7	R20, R21, R24, R25, R28, R29, R32	100k	
3	R11, R12, R13	220k	
3	R15, R19, R30	1M	
4	RV1, RV2, RV4, RV6	10k	Alpha RD901F-40-15R1-B10K
1	RV3	100k	Alpha RD901F-40-15R1-B100K
3	RV5, RV7, RV8	100k	Bourns 3296X / SR Passives T910X-100K
1	U1	LM13700	DIP-16
2	U2, U3	TL074	DIP-14
1	U4	L78L09	TO92
1	U5	LM79L09	TO92
2			14-pin DIP socket (optional)
1			16-pin DIP socket (optional)

Board render

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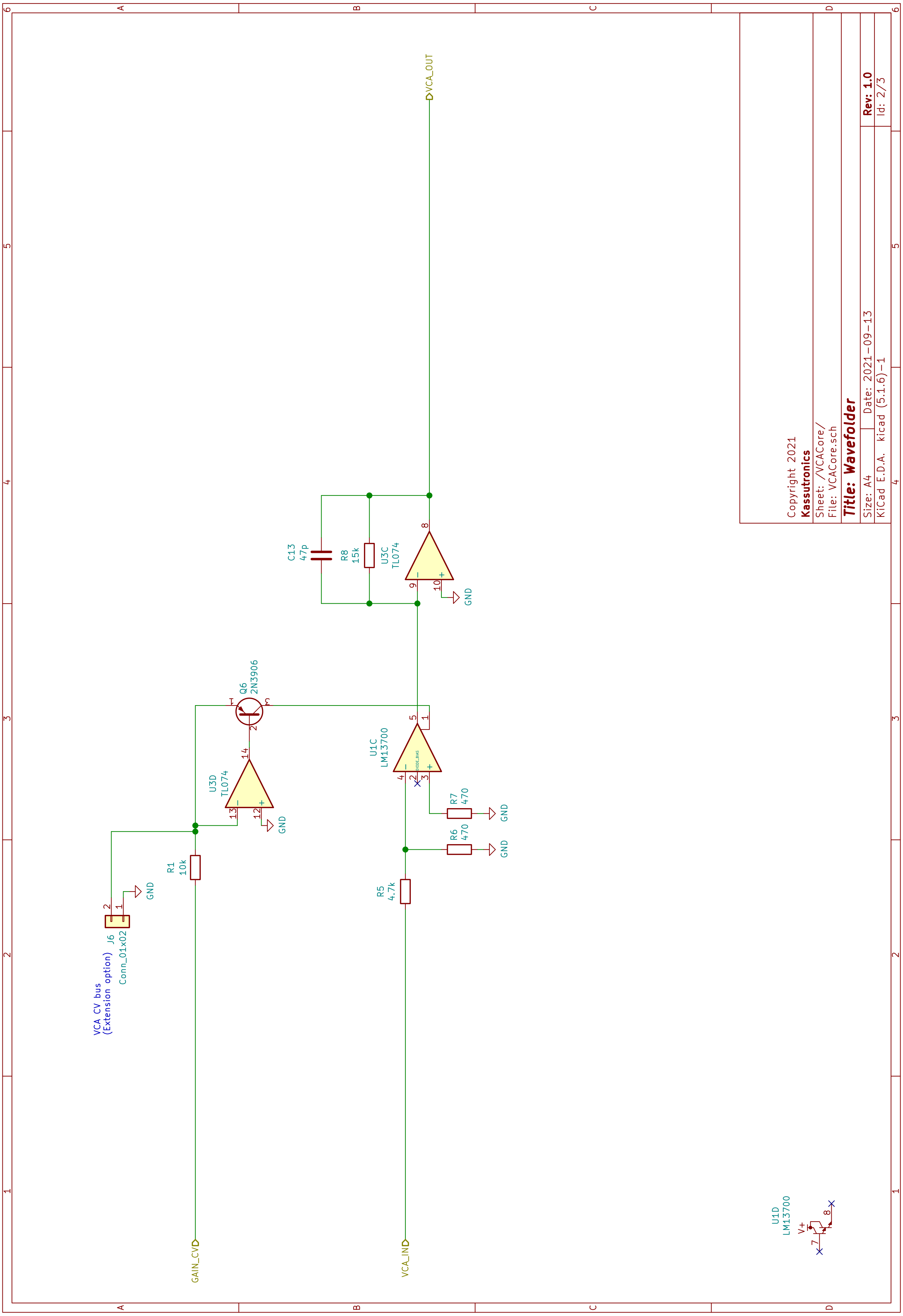
Id: 1/3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C13
47p
R8
15k
U3C
TL074
GND
Q6
2N3906
U1C
LM13700
U3D
TL074
R7
470
R6
470
R1
10k
R5
4.7k
J6
Conn_01x02
VCA CV bus
(Extension option)
GAIN_CV
VCA_IN
U1D
LM13700
V+
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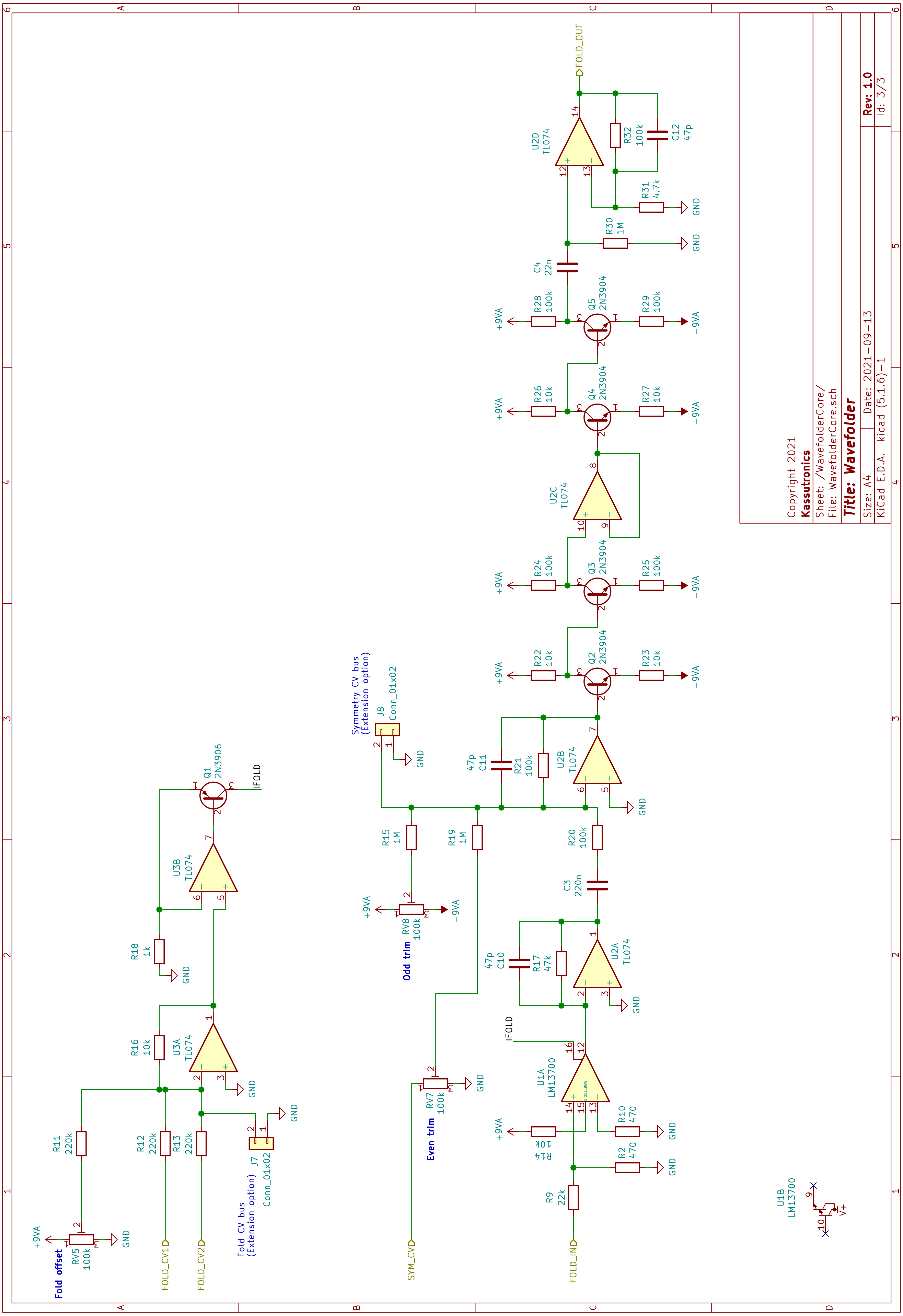
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Kassutronics
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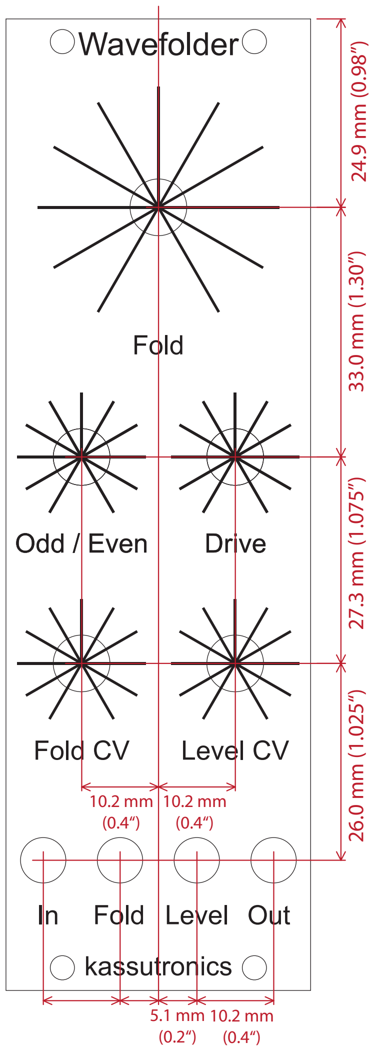
Rev: 1.0
KiCad E.D.A. kicad (5.1.6)-1
Id: 3/3
Fold offset
Odd trim
Even trim
Symmetry CV bus (Extension option)
Fold CV bus (Extension option)
FOLD_OUT
FOLD_IN
FOLD_CV1
FOLD_CV2
SYM_CV

Front panel dimensions

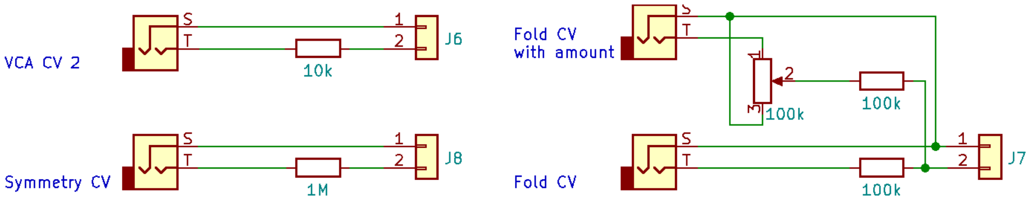


Possible modifications

Adding extra CV inputs

The PCB has three break-out locations where optional extra control voltage inputs can be connected. These are labeled on the backside of the PCB as **J6** (VCA CV), **J7** (Fold CV), and **J8** (Symmetry CV). The symmetry CV input gives voltage control over the Odd / Even control. These can be used to add extra CV inputs on an extended or separate panel, optionally with attenuators.

Each of these expansion headers has a dedicated ground connection as pin 1 (square solder pad), and the signal input on pin 2. These are all virtual ground nodes of the respective summing opamp, which means that a series resistor should be soldered in-line to the actual CV input. The following schematic shows several ways this can be connected, as well as the recommended resistor value for each input.



The left panel shows the basic connection with a single series resistor. To avoid unwanted noise pickup, it is recommended to solder the resistor close to the wavefolder PCB connector. Between the resistor and the jack a longer wire can be used if needed, ideally with a dedicated parallel ground wire for each jack.

The right panel shows how multiple inputs can be connected to a single expanion point, with a dedicated series resistor for each. It also shows how a potentiometer can be connected to form a CV attenuator. In the drawing here, pin 1 of the potentiometer refers to the clockwise pin.

The different connection possibilities shown above can be used in any combination for all three inputs, always using the correct series resistor value for that input. Potentiometer value can be always 100k.

Revision history

Board revisions

1.0 First public version

Documentation revisions

A Initial documentation for board revision 1.0.

Contact

Check for updated documentation and other information on my blog at kassu2000.blogspot.com. I am always happy to answer questions and receive feedback at kassutronics@gmail.com.