Kocmoc SVF Eurorack Module Build Instructions for V1.6

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1 Introduction

Kocmoc SVF module is a SSM2164 VCA chip based voltage controlled filter in Eurorack format. Kocmoc Eurorack modules are licenced under CERN Open Hardware Licence version 2 - Strongly Reciprocal licence with all rights reserved by the copyright holder.

Kocmoc Eurorack Git repository

You can find build instructions, board layouts and schematics at

https://www.github.com/janne808/Kocmoc-Eurorack

2 Theory of operation

The filter circuit is based on a classic 12dB/oct state variable filter circuit made popular by [Chamberlin]. The voltage control is implemented by voltage controlled amplifiers using the SSM2164 chip (or equivalent modern clone).

The two voltage controlled inverting integrators responsible for the filter operation follow the SSI2164 application note example from [Allaert].

2.1 State variable filter block diagram

The classic voltage controlled SVF circuit is implemented with the following block diagram

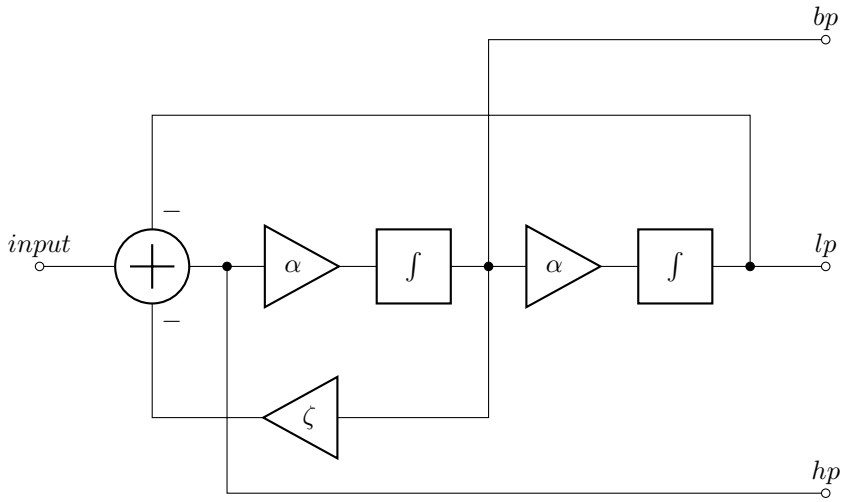

Figure 1: Voltage controlled state variable filter block diagram

which follows the ordinary differential equation (ODE)

$$\begin{aligned} x_1'(t) &= \alpha(input(t) - \zeta x_1(t) - x_2(t)) \\ x_2'(t) &= \alpha x_1(t) \end{aligned} \tag{1}$$

where x_1 and x_2 are the first and second integrator variables respectively, ζ is the damping factor and α is the integration rate.

2.2 Fixed interval limiting for integrator

For a practical synthesizer filter, the integration needs to be limited to a fixed interval by some method. Otherwise the process will result in voltages that get stuck at rail voltages and other instabilities.

In this filter the limiter is implemented in the first integrator with a diode soft clipper circuit in parallel with the feedback integration capacitor. This results in added even harmonics and stable operation even with extreme input drive and resonance settings.

The following circuit implements the inverting soft clipping integrator

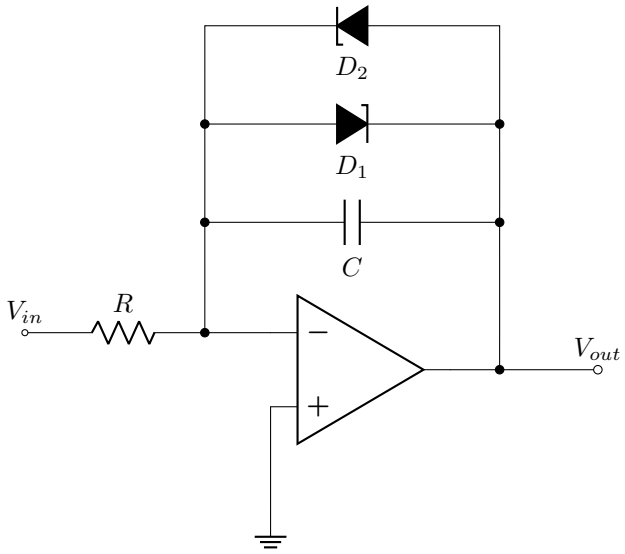

Figure 2: Inverting soft clipping integrator

which follows the nonlinear ODE (assuming diodes are modelled with the forward current approximation)

$$V'_{out} = -\frac{1}{RC}V_{in} - \frac{I_s}{C}\sinh\frac{V_{out}}{\eta V_t} \tag{2}$$

where I_s is the diode reverse saturation current, η is the diode emission coefficient and V_t is the diode thermal voltage.

The above ODE can be solved using a numerical trapezoidal ODE solver. Inserting silicon diode parameters for the diode clipping circuit part of the equation results in a solution which is illustrated in figure 3.

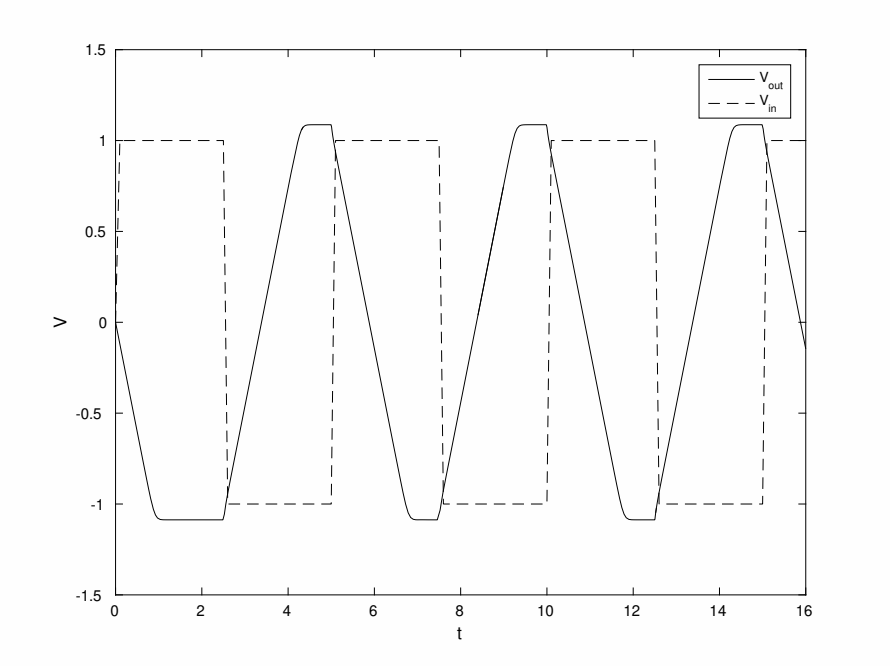

Figure 3: Numerical solution to inverting soft clipping integrator ODE model

Implementing the soft clipping integrator in the filter results in the following final nonlinear ODE model

$$\begin{aligned} x_1'(t) &= \alpha(input(t) - \zeta x_1(t) - x_2(t)) - a \sinh \frac{x_1(t)}{b} \\ x_2'(t) &= \alpha x_1(t) \end{aligned} \tag{3}$$

It should be noted that the above model is idealized and differs from the practical implementation. The integrators on the board are both inverting ($\alpha < 0$) which should be taken into account when analysing the circuit operation.

2.3 Boosting resonance

In state variable filters the damping factor control ζ is reversed: Lower factors result in more feedback, up to self-oscillation (with diode clipping limited integration), meaning damping factor can also be negative to drive the resonance oscillation further.

This can be exploited in a practical circuit, where absolute zero damping factor is hard to realise with resistive voltage dividers (such as potentiometers and board traces with non-zero stray resistances). The R9 and R10 voltage divider

fed in the opposite phase of the VR1 and R11 voltage divider input of the first integrator stage operational amplifier summer IC3G1 realises through zero modulation of the damping factor ζ.

3 Build instructions

The PCB consists of panelized boards, one for front panel connectors and one for the power connector, integrators and input/output buffering. The boards are connected together with two 10-pin headers and a 11mm M3 PCB standoff.

It is important to mount the 9mm potentiometers, Thonkiconn jack sockets and the M3 board standoff first *without soldering* to the control PCB and only after that attach them to the front panel with appropriate nuts.

The building process should follow the following order

- Populate and solder resistors and ferrite beads on both boards
- Populate and solder diodes
- Populate and solder capacitors on both boards
- Populate and solder integrated circuits
- Break the panelized boards in half and trim off mousebites
- Solder power connector and headers (make sure the pins match from schematics and board layout)
- Mount 11mm M3 PCB standoff with a M3 screw on the upper control board
- Mount the snap-in 9mm Alpha potentiometers VR4 and VR1 *without soldering*
- Mount the snap-in 9mm Alpha trimmers VR3, VR5 and VR2 *without soldering*
- Mount Thonkiconn jack sockets U1, U2, U3, U4, U5 and U6 *without soldering*
- Mount the front panel
- Fingertighten socket and potentiometer nuts to the panel
- Solder in through-hole sockets and potentiometers
- Tighten nuts fully
- Mount potentiometer caps for VR4 and VR1
- Connect the boards with the headers and M3 screw for the PCB standoff

3.1 SSM2164 issues

The original Analog Devices SSM2164 has a fault which will burn the chip if the negative power supply rail becomes unconnected. This fault has been corrected in modern clones from SSI and Alpha but remains in Coolaudio V2164.

[Johnson] has researched the failure (with Oscar Salas) and proposed a fix which will be implemented in the next version of the board.

3.2 Capacitors

Capacitors C29 and C30 are used for compensating parasitic effects of the PCB and component leads and should be left unpopulated and populated only if needed. The parasitic effects manifest themselves as increased resonance at higher cutoff frequencies.

3.3 Power connector and headers

Please note that version 1.5 of the boards had their power connector and header component footprint graphics mirrored by mistake. For the header pinouts this makes no difference but confusion could arise for the power connector. In any case, if a shrouded power connector is used, it should be mounted on the bottom side of the main board with the cutout slot facing away from the board.

Follow and match the board and schematic graphics to the Eurorack power connector standard to make sure the pins deliver proper voltages to the board. The board is diode protected against reverse voltage.

References

[Chamberlin] Hal Chamberlin. *Musical Applications of Microcomputers*. Hayden Books, 1985.

[Allaert] Jeroen Allaert. *Designing Voltage Controlled Filters for Synthesizers with the SSI2164*. Sound Semiconductor Inc., 2019
`http://www.soundsemiconductor.com/downloads/AN701.pdf`

[Johnson] Neil Johnson. *SSM2164/SSI2164 Information*. Neil Johnson, 2021
`https://www.njohnson.co.uk/index.php?menu=2&submenu=2&subsubmenu=3`

A BOM

Through-hole board BOM

Part	Value	Device	Package	Description
C1	220p	C-EU050-025X075	C050-025X075	CAPACITOR, European symbol
C2	220p	C-EU050-025X075	C050-025X075	CAPACITOR, European symbol
C3	22p	C-EU050-025X075	C050-025X075	CAPACITOR, European symbol
C4	22p	C-EU050-025X075	C050-025X075	CAPACITOR, European symbol
C5	680p	C-EU050-025X075	C050-025X075	CAPACITOR, European symbol
C6	680p	C-EU050-025X075	C050-025X075	CAPACITOR, European symbol
C7	1u	CPOL-EUE2,5-6E	E2,5-6E	POLARIZED CAPACITOR, European symbol
C8	560p	C-EU050-025X075	C050-025X075	CAPACITOR, European symbol
C9	100n	C-EU050-025X075	C050-025X075	CAPACITOR, European symbol
C10	22p	C-EU050-025X075	C050-025X075	CAPACITOR, European symbol
C11	2.2u	CPOL-EUE2,5-6E	E2,5-6E	POLARIZED CAPACITOR, European symbol
C12	22p	C-EU050-025X075	C050-025X075	CAPACITOR, European symbol
C13	2.2u	CPOL-EUE2,5-6E	E2,5-6E	POLARIZED CAPACITOR, European symbol
C14	22p	C-EU050-025X075	C050-025X075	CAPACITOR, European symbol
C15	10u	CPOL-EUE2,5-6E	E2,5-6E	POLARIZED CAPACITOR, European symbol
C16	10u	CPOL-EUE2,5-6E	E2,5-6E	POLARIZED CAPACITOR, European symbol
C17	100n	C-EU050-025X075	C050-025X075	CAPACITOR, European symbol
C18	100n	C-EU050-025X075	C050-025X075	CAPACITOR, European symbol
C19	100n	C-EU050-025X075	C050-025X075	CAPACITOR, European symbol
C20	100n	C-EU050-025X075	C050-025X075	CAPACITOR, European symbol
C21	100n	C-EU050-025X075	C050-025X075	CAPACITOR, European symbol
C22	100n	C-EU050-025X075	C050-025X075	CAPACITOR, European symbol
C23	100n	C-EU050-025X075	C050-025X075	CAPACITOR, European symbol
C24	100n	C-EU050-025X075	C050-025X075	CAPACITOR, European symbol
C27	100n	C-EU050-025X075	C050-025X075	CAPACITOR, European symbol
C28	100n	C-EU050-025X075	C050-025X075	CAPACITOR, European symbol
C29	5p	C-EU050-025X075	C050-025X075	CAPACITOR, European symbol
C30	5p	C-EU050-025X075	C050-025X075	CAPACITOR, European symbol
D1	4.7	ZENER-DIODEDO34-7	DO34Z7	Z-Diode
D2	4.7	ZENER-DIODEDO34-7	DO34Z7	Z-Diode
D3	1N4148DO35-7	1N4148DO35-7	DO35-7	DIODE
D4	4.7	ZENER-DIODEDO34-7	DO34Z7	Z-Diode
D5	1N5817	SCHOTTKY-DIODEDO35-7	DO35-7	Schottky Diode
D6	1N5817	SCHOTTKY-DIODEDO35-7	DO35-7	Schottky Diode
HEADR1		10PIN_BACKSIDE	10PIN_BACKSIDE	PIN HEADER
HEADR2		10PIN_BACKSIDE	10PIN_BACKSIDE	PIN HEADER
HEADR3		10PIN_BACKSIDE	10PIN_BACKSIDE	PIN HEADER
HEADR4		10PIN_BACKSIDE	10PIN_BACKSIDE	PIN HEADER
IC1	SSM2164P	SSM2164P	DIL16	
IC2	TL072	OPAMP-DUALDIP	DIP08	Generic op-amp footprint
IC3	TL072	OPAMP-DUALDIP	DIP08	Generic op-amp footprint
IC4	TL072	OPAMP-DUALDIP	DIP08	Generic op-amp footprint
IC5	TL072	OPAMP-DUALDIP	DIP08	Generic op-amp footprint
IC6	TL072	OPAMP-DUALDIP	DIP08	Generic op-amp footprint
J1		CONN_05X2SHD	2X5-SHROUDED	Multi connection point. Often used as Generic Header-pin fo
L1	FERRITE	FB-085	FB-085	FERRITE BEAD
L2	FERRITE	FB-085	FB-085	FERRITE BEAD
R1	15k	R-EU_0207/2V	0207/2V	RESISTOR, European symbol
R2	15k	R-EU_0207/2V	0207/2V	RESISTOR, European symbol
R3	15k	R-EU_0207/2V	0207/2V	RESISTOR, European symbol
R4	15k	R-EU_0207/2V	0207/2V	RESISTOR, European symbol
R5	100k	R-EU_0207/2V	0207/2V	RESISTOR, European symbol
R6	33k	R-EU_0207/2V	0207/2V	RESISTOR, European symbol
R7	360	R-EU_0207/2V	0207/2V	RESISTOR, European symbol
R8	360	R-EU_0207/2V	0207/2V	RESISTOR, European symbol
R9	3k	R-EU_0207/2V	0207/2V	RESISTOR, European symbol
R10	30k	R-EU_0207/2V	0207/2V	RESISTOR, European symbol
R11	4k	R-EU_0207/2V	0207/2V	RESISTOR, European symbol
R12	15k	R-EU_0207/2V	0207/2V	RESISTOR, European symbol
R13	100k	R-EU_0207/2V	0207/2V	RESISTOR, European symbol
R14	100k	R-EU_0207/2V	0207/2V	RESISTOR, European symbol
R15	100k	R-EU_0207/2V	0207/2V	RESISTOR, European symbol

R16	820	R-EU_0207/2V	0207/2V	RESISTOR, European symbol
R17	100k	R-EU_0207/2V	0207/2V	RESISTOR, European symbol
R18	100k	R-EU_0207/2V	0207/2V	RESISTOR, European symbol
R19	270k	R-EU_0207/2V	0207/2V	RESISTOR, European symbol
R20	68k	R-EU_0207/2V	0207/2V	RESISTOR, European symbol
R21	22k	R-EU_0207/2V	0207/2V	RESISTOR, European symbol
R22	1k	R-EU_0207/2V	0207/2V	RESISTOR, European symbol
R23	33k	R-EU_0207/2V	0207/2V	RESISTOR, European symbol
R24	1k	R-EU_0207/2V	0207/2V	RESISTOR, European symbol
R25	22k	R-EU_0207/2V	0207/2V	RESISTOR, European symbol
R26	1k	R-EU_0207/2V	0207/2V	RESISTOR, European symbol
R27	33k	R-EU_0207/2V	0207/2V	RESISTOR, European symbol
R28	22k	R-EU_0207/2V	0207/2V	RESISTOR, European symbol
R29	2.7k	R-EU_0207/2V	0207/2V	RESISTOR, European symbol
R30	17k	R-EU_0207/2V	0207/2V	RESISTOR, European symbol
U1	THONKICONNNEW	THONKICONNNEW	WQP-PJ301M-12_JACK	3.5mm socket for Eurorack modular synths
U2	THONKICONNNEW	THONKICONNNEW	WQP-PJ301M-12_JACK	3.5mm socket for Eurorack modular synths
U3	THONKICONNNEW	THONKICONNNEW	WQP-PJ301M-12_JACK	3.5mm socket for Eurorack modular synths
U4	THONKICONNNEW	THONKICONNNEW	WQP-PJ301M-12_JACK	3.5mm socket for Eurorack modular synths
U5	THONKICONNNEW	THONKICONNNEW	WQP-PJ301M-12_JACK	3.5mm socket for Eurorack modular synths
U6	THONKICONNNEW	THONKICONNNEW	WQP-PJ301M-12_JACK	3.5mm socket for Eurorack modular synths
VR1	A100k	9MM_SNAP-IN_POT_	9MM_SNAP-IN_POT	9mm vertical snap-in pot, Alpha / Panasonic style
VR2	A100k	9MM_SNAP-IN_POT_	9MM_SNAP-IN_POT	9mm vertical snap-in pot, Alpha / Panasonic style
VR3	B10k	9MM_SNAP-IN_POT_	9MM_SNAP-IN_POT	9mm vertical snap-in pot, Alpha / Panasonic style
VR4	B10k	9MM_SNAP-IN_POT_	9MM_SNAP-IN_POT	9mm vertical snap-in pot, Alpha / Panasonic style
VR5	B100k	9MM_SNAP-IN_POT_	9MM_SNAP-IN_POT	9mm vertical snap-in pot, Alpha / Panasonic style

Surface mount device board BOM

Part	Value	Device	Package	Description
C1	220p	C-EUC0603	C0603	CAPACITOR, European symbol
C2	220p	C-EUC0603	C0603	CAPACITOR, European symbol
C3	22p	C-EUC0603	C0603	CAPACITOR, European symbol
C4	22p	C-EUC0603	C0603	CAPACITOR, European symbol
C5	680p	C-EUC0603	C0603	CAPACITOR, European symbol
C6	680p	C-EUC0603	C0603	CAPACITOR, European symbol
C7	1u	CPOL-EUB	PANASONIC_B	POLARIZED CAPACITOR, European symbol
C8	560p	C-EUC0603	C0603	CAPACITOR, European symbol
C9	100n	C-EUC0603	C0603	CAPACITOR, European symbol
C10	22p	C-EUC0603	C0603	CAPACITOR, European symbol
C11	2.2u	CPOL-EUB	PANASONIC_B	POLARIZED CAPACITOR, European symbol
C12	22p	C-EUC0603	C0603	CAPACITOR, European symbol
C13	2.2u	CPOL-EUB	PANASONIC_B	POLARIZED CAPACITOR, European symbol
C14	22p	C-EUC0603	C0603	CAPACITOR, European symbol
C15	10u	CPOL-EUB	PANASONIC_B	POLARIZED CAPACITOR, European symbol
C16	10u	CPOL-EUB	PANASONIC_B	POLARIZED CAPACITOR, European symbol
C17	100n	C-EUC0603	C0603	CAPACITOR, European symbol
C18	100n	C-EUC0603	C0603	CAPACITOR, European symbol
C19	100n	C-EUC0603	C0603	CAPACITOR, European symbol
C20	100n	C-EUC0603	C0603	CAPACITOR, European symbol
C21	100n	C-EUC0603	C0603	CAPACITOR, European symbol
C22	100n	C-EUC0603	C0603	CAPACITOR, European symbol
C23	100n	C-EUC0603	C0603	CAPACITOR, European symbol
C24	100n	C-EUC0603	C0603	CAPACITOR, European symbol
C27	100n	C-EUC0603	C0603	CAPACITOR, European symbol
C28	100n	C-EUC0603	C0603	CAPACITOR, European symbol
C29	5p	C-EUC0603	C0603	CAPACITOR, European symbol
C30	5p	C-EUC0603	C0603	CAPACITOR, European symbol
D1	4.7	DIODE_ZENER-DIODESOD80C	DIODE_SOD80C	Z-Diode
D2	4.7	DIODE_ZENER-DIODESOD80C	DIODE_SOD80C	Z-Diode
D3	1N4148WX-TP	1N4148WX-TP	SOD323R-INFINEON	
D4	4.7	DIODE_ZENER-DIODESOD80C	DIODE_SOD80C	Z-Diode
D5	1N5817	SCHOTTKY-DIODEDO35-7	DO35-7	Schottky Diode
D6	1N5817	SCHOTTKY-DIODEDO35-7	DO35-7	Schottky Diode
HEADR1		10PIN_BACKSIDE	10PIN_BACKSIDE	PIN HEADER
HEADR2		10PIN_BACKSIDE	10PIN_BACKSIDE	PIN HEADER
HEADR3		10PIN_BACKSIDE	10PIN_BACKSIDE	PIN HEADER
HEADR4		10PIN_BACKSIDE	10PIN_BACKSIDE	PIN HEADER
IC1	SSM2164S	SSM2164S	SOIC16N	
IC2	TL072	OPAMP-DUALU	SO08	Generic op-amp footprint
IC3	TL072	OPAMP-DUALU	SO08	Generic op-amp footprint
IC4	TL072	OPAMP-DUALU	SO08	Generic op-amp footprint
IC5	TL072	OPAMP-DUALU	SO08	Generic op-amp footprint
IC6	TL072	OPAMP-DUALU	SO08	Generic op-amp footprint
J1		CONN_05X2SHD	2X5-SHROUDED	Multi connection point. Often used as Generic Header-pin
L1	FERRITE	EXC3BP	0603	Chip Bead Core
L2	FERRITE	EXC3BP	0603	Chip Bead Core
R1	15k	R-EU_R0603	R0603	RESISTOR, European symbol
R2	15k	R-EU_R0603	R0603	RESISTOR, European symbol
R3	15k	R-EU_R0603	R0603	RESISTOR, European symbol
R4	15k	R-EU_R0603	R0603	RESISTOR, European symbol
R5	100k	R-EU_R0603	R0603	RESISTOR, European symbol
R6	33k	R-EU_R0603	R0603	RESISTOR, European symbol
R7	360	R-EU_R0603	R0603	RESISTOR, European symbol
R8	360	R-EU_R0603	R0603	RESISTOR, European symbol
R9	3k	R-EU_R0603	R0603	RESISTOR, European symbol
R10	30k	R-EU_R0603	R0603	RESISTOR, European symbol
R11	4k	R-EU_R0603	R0603	RESISTOR, European symbol
R12	15k	R-EU_R0603	R0603	RESISTOR, European symbol
R13	100k	R-EU_R0603	R0603	RESISTOR, European symbol
R14	100k	R-EU_R0603	R0603	RESISTOR, European symbol
R15	100k	R-EU_R0603	R0603	RESISTOR, European symbol
R16	820	R-EU_R0603	R0603	RESISTOR, European symbol
R17	100k	R-EU_R0603	R0603	RESISTOR, European symbol

R18	100k	R-EU_R0603	R0603	RESISTOR, European symbol
R19	270k	R-EU_R0603	R0603	RESISTOR, European symbol
R20	68k	R-EU_R0603	R0603	RESISTOR, European symbol
R21	22k	R-EU_R0603	R0603	RESISTOR, European symbol
R22	1k	R-EU_R0603	R0603	RESISTOR, European symbol
R23	33k	R-EU_R0603	R0603	RESISTOR, European symbol
R24	1k	R-EU_R0603	R0603	RESISTOR, European symbol
R25	22k	R-EU_R0603	R0603	RESISTOR, European symbol
R26	1k	R-EU_R0603	R0603	RESISTOR, European symbol
R27	33k	R-EU_R0603	R0603	RESISTOR, European symbol
R28	22k	R-EU_R0603	R0603	RESISTOR, European symbol
R29	2.7k	R-EU_R0603	R0603	RESISTOR, European symbol
R30	17k	R-EU_R0603	R0603	RESISTOR, European symbol
U1	THONKICONNNEW	THONKICONNNEW	WQP-PJ301M-12_JACK	3.5mm socket for Eurorack modular synths
U2	THONKICONNNEW	THONKICONNNEW	WQP-PJ301M-12_JACK	3.5mm socket for Eurorack modular synths
U3	THONKICONNNEW	THONKICONNNEW	WQP-PJ301M-12_JACK	3.5mm socket for Eurorack modular synths
U4	THONKICONNNEW	THONKICONNNEW	WQP-PJ301M-12_JACK	3.5mm socket for Eurorack modular synths
U5	THONKICONNNEW	THONKICONNNEW	WQP-PJ301M-12_JACK	3.5mm socket for Eurorack modular synths
U6	THONKICONNNEW	THONKICONNNEW	WQP-PJ301M-12_JACK	3.5mm socket for Eurorack modular synths
VR1	A100k	9MM_SNAP-IN_POT_	9MM_SNAP-IN_POT	9mm vertical snap-in pot, Alpha / Panasonic style
VR2	A100k	9MM_SNAP-IN_POT_	9MM_SNAP-IN_POT	9mm vertical snap-in pot, Alpha / Panasonic style
VR3	B10k	9MM_SNAP-IN_POT_	9MM_SNAP-IN_POT	9mm vertical snap-in pot, Alpha / Panasonic style
VR4	B10k	9MM_SNAP-IN_POT_	9MM_SNAP-IN_POT	9mm vertical snap-in pot, Alpha / Panasonic style
VR5	B100k	9MM_SNAP-IN_POT_	9MM_SNAP-IN_POT	9mm vertical snap-in pot, Alpha / Panasonic style

B Schematics

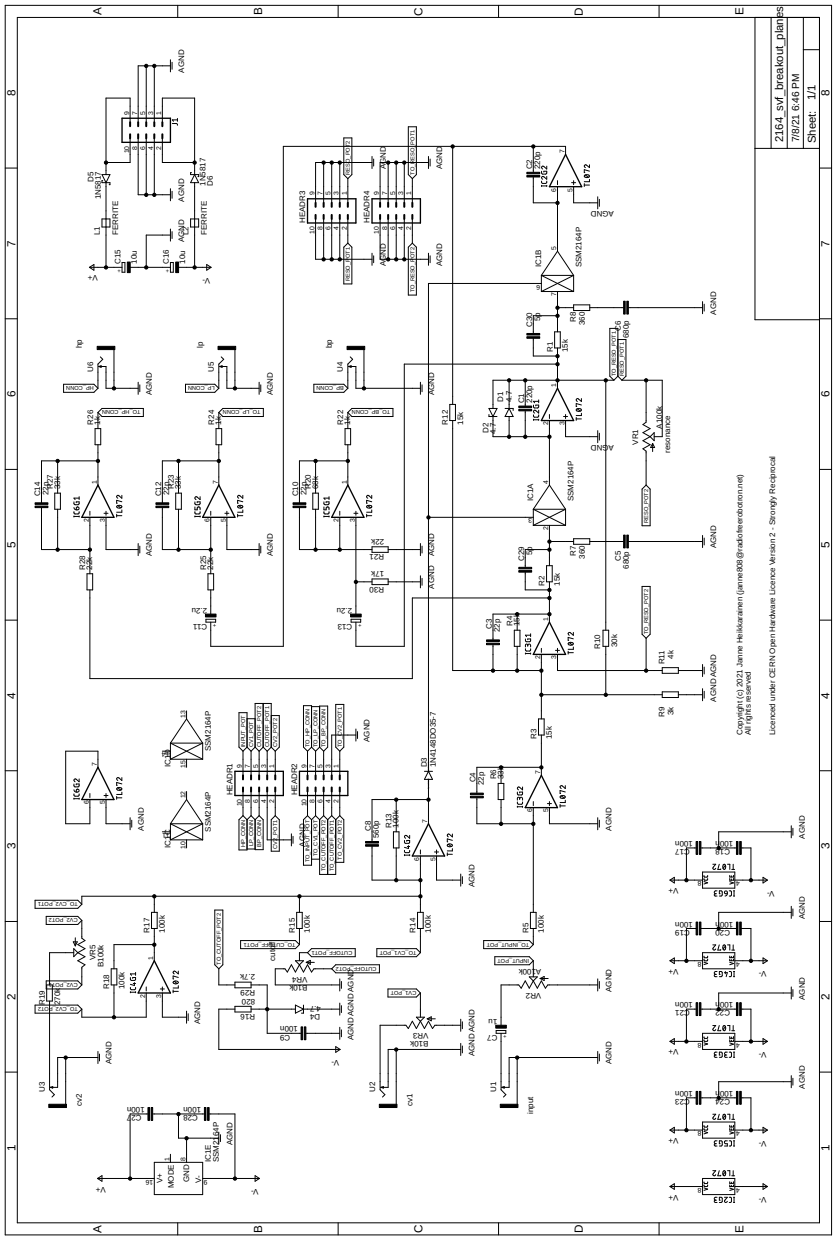

Figure 4: Through-hole board schematic.

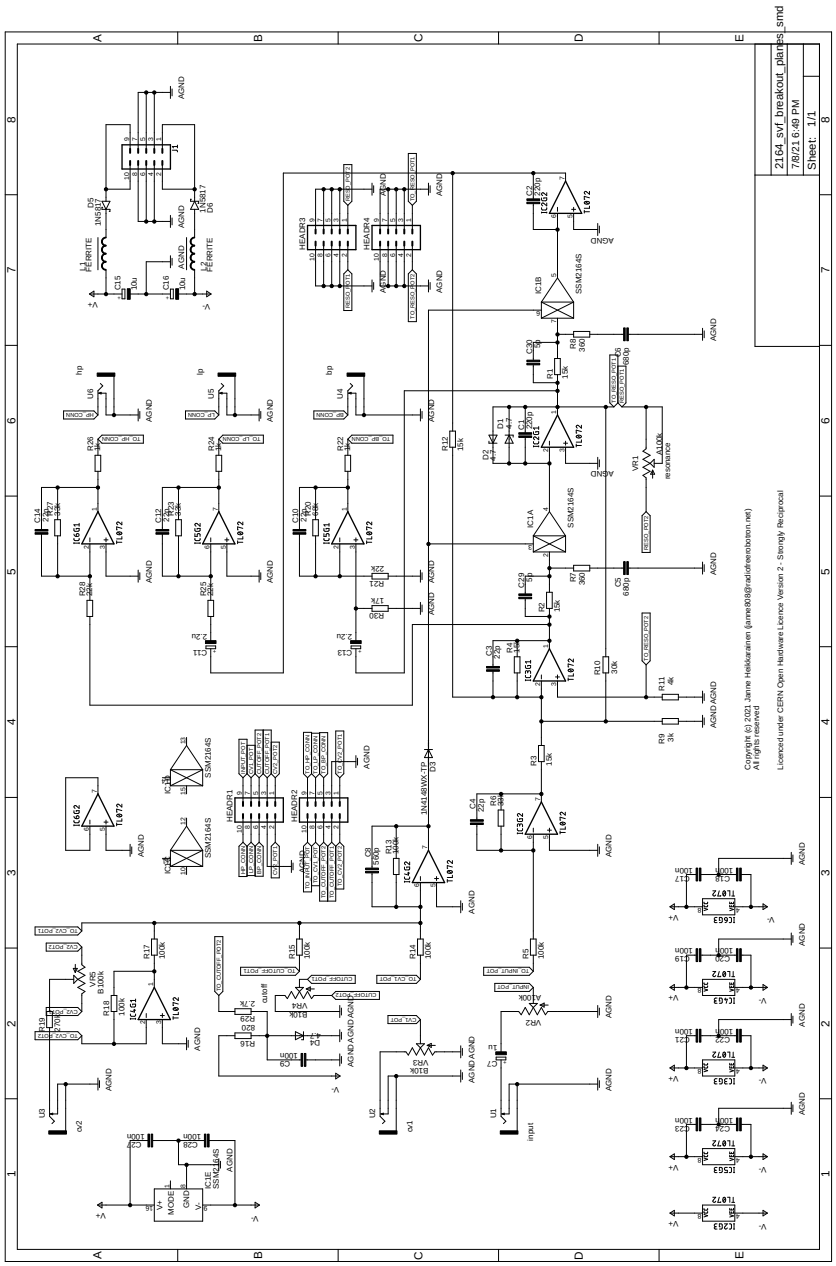

Figure 5: Surface mount device board schematic.

C Board component placement layouts

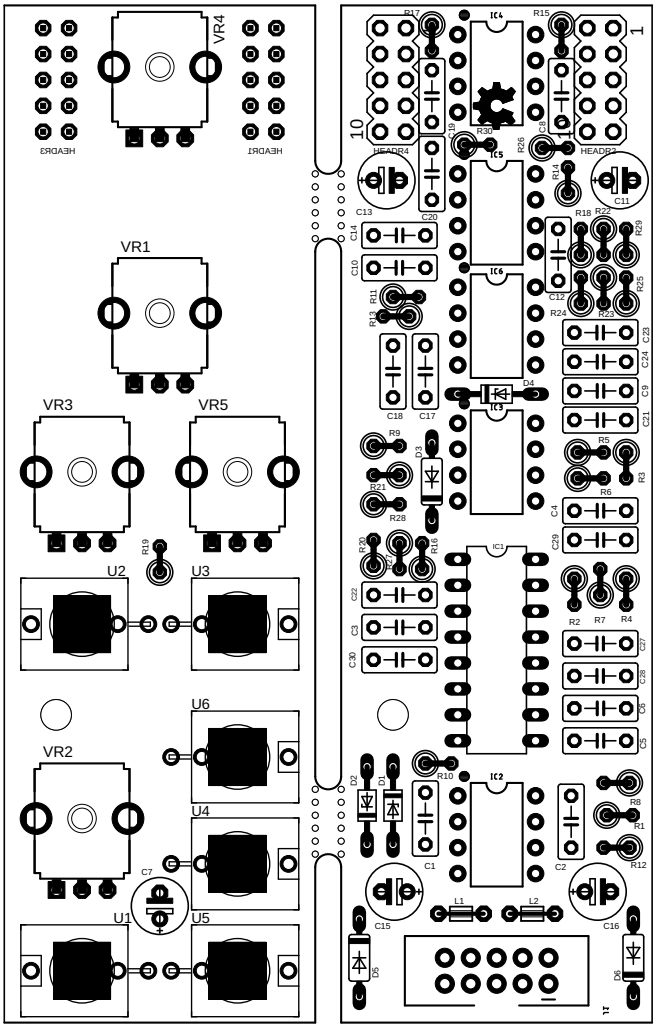

Figure 6: Through-hole board component placement for V1.6.

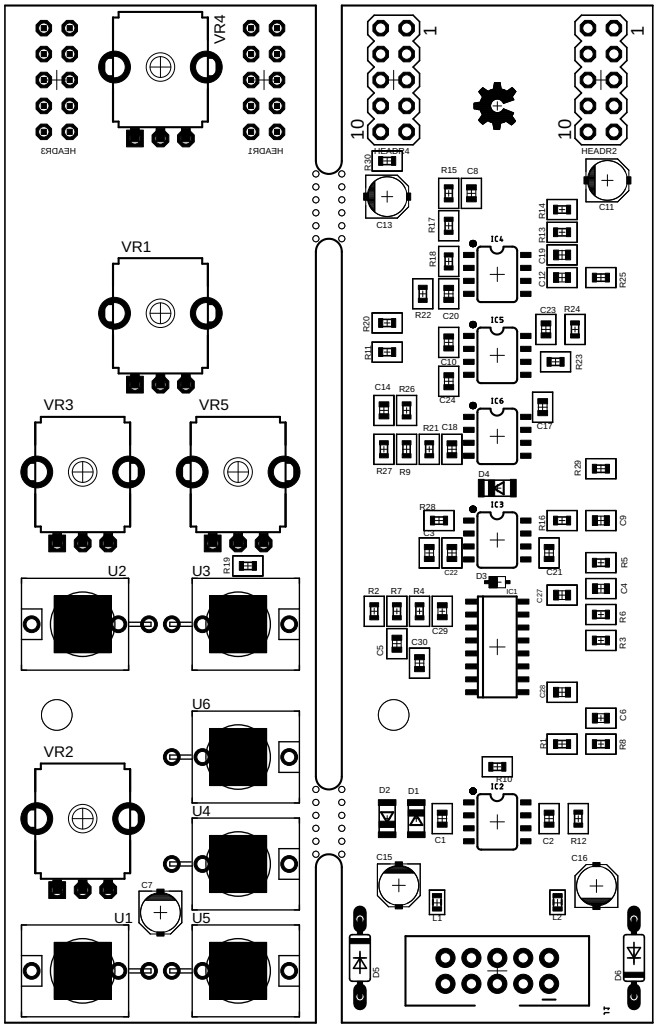

Figure 7: Surface mount device board component placement for V1.6.