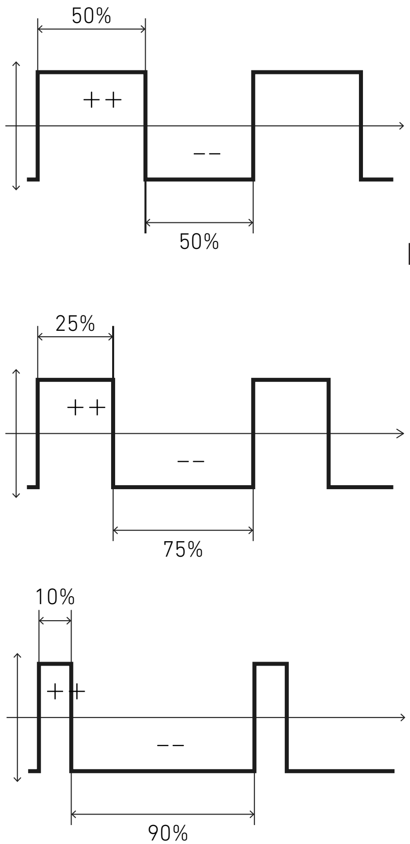
The TH-VCO1 is a voltage controlled oscillator, with a triangle Schmitt-Trigger Integrator core designed by Thomas Henry.

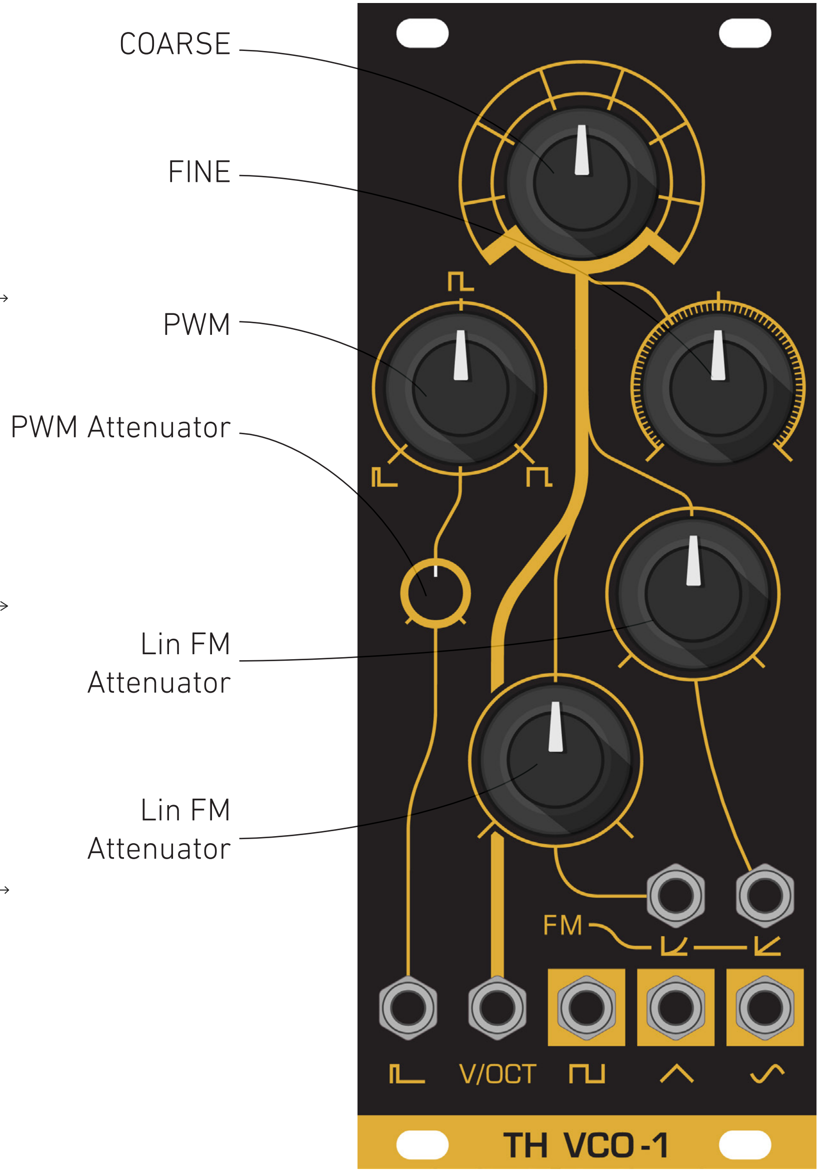
This core yields is a very stable Oscillator capable to output **TRIANGLE (⋀)**, **SINE (∿)** and **PWM (⊓⊔)**[1] waves. The base oscillation frequency of the oscillator may be changed via the **COARSE** and **FINE** Frequency knobs.

The Pitch of the VCO1 can also be controlled with an Control Voltage (CV) present at the **V/OCT** input. This input tracks with 1V per Octave and does so accurately for at least 8 octaves if the mdoule is calibrated well.

There are two **FM**[2] Inputs with **EXPONENTIAL (⦦)** and **LINEAR (⦣)** characteristics. Try plugging one of the outputs or the output of a second VCO back into a FM input and turn up the according **ATTENUATOR.**

With the **PWM KNOB** the pulse width of the PWM Output may be shifted from 0 to 100% (see diagrams to the right), resulting in a change of overtone structure. There is a **PWM INPUT (⌊_)** which enables voltage control of the Pulsewidth.





1 Pulse-Width-Modulation
2 Frequency Modulation

BOM: TH-VCO1 COMPONENTS PCB [1/3]

QTY	VALUE	DEVICE	PARTS	DESCRIPTION
2	100k	Resistor 7mm	☐ R13 ☐ R20	Metall film resistor
6	10k	Resistor 7mm	☐ R4 ☐ R5 ☐ R12 ☐ R19 ☐ R22 ☐ R23	Metall film resistor
2	12k	Resistor 7mm	☐ R26 ☐ R27	Metall film resistor
1	150k	Resistor 7mm	☐ R36	Metall film resistor
2	18k	Resistor 7mm	☐ R17 ☐ R25	Metall film resistor
1	1M	Resistor 7mm	☐ R10	Metall film resistor
1	1k	Resistor 7mm	☐ R1	Metall film resistor
3	2.2k	Resistor 7mm	☐ R21 ☐ R28 ☐ R30	Metall film resistor
2	2.2m	Resistor 7mm	☐ R3 ☐ R31	Metall film resistor
1	20k	Resistor 7mm	☐ R16	Metall film resistor
1	22k	Resistor 7mm	☐ R9	Metall film resistor
1	27k	Resistor 7mm	☐ R15	Metall film resistor
1	390R	Resistor 7mm	☐ R24	Metall film resistor
1	47R	Resistor 7mm	☐ R7	Metall film resistor
1	5.1k	Resistor 7mm	☐ R18	Metall film resistor
1	820R	Resistor 7mm	☐ R8	Metall film resistor
1	2k	TEMPCO	☐ R2	Tempco Resistor (prevents temperature drift, may be replaced with regular resistor)
2	1N4001 or 1N4004	1N4001 or 1N4004	☐ D5 ☐ D6	Rectifier Diode
1	1N4148	SMALL_DIODEDO35-7	☐ D1	Small Signal Diode

BOM: TH-VCO1 COMPONENTS PCB [2/3]

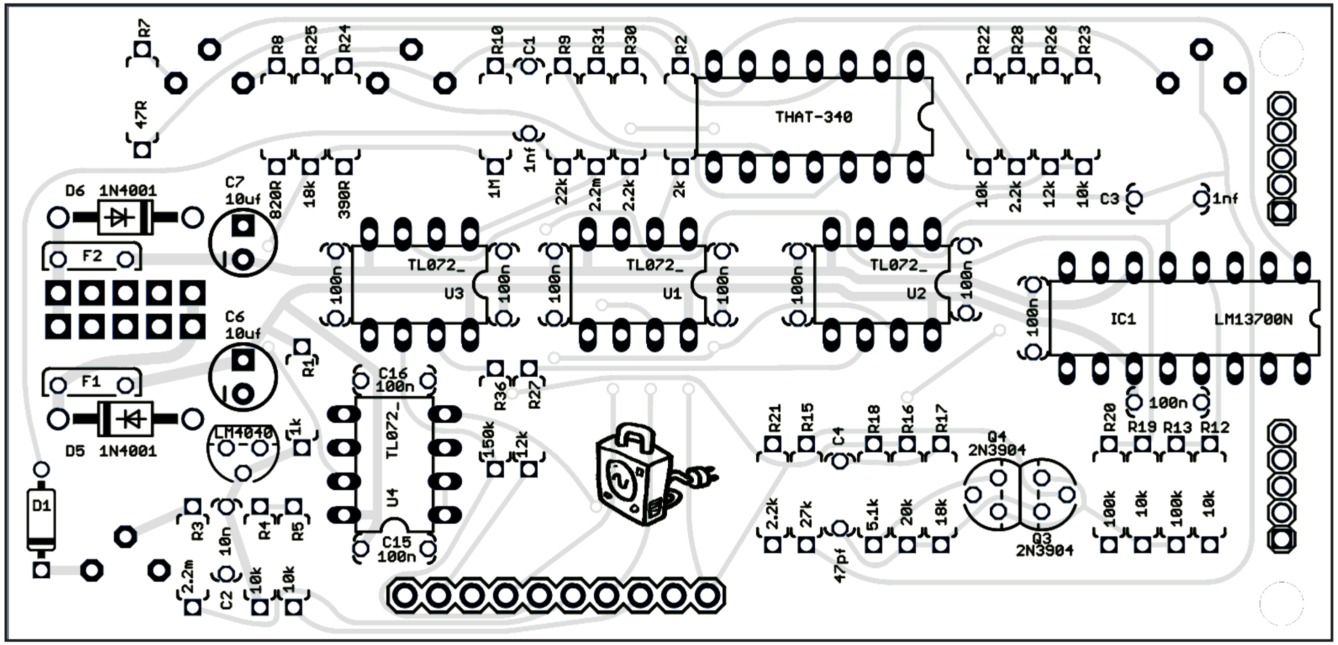
QTY	VALUE	DEVICE	PARTS	DESCRIPTION
2	10uf	CAP_POLPTH2	☐ C6 ☐ C7	Electrolytic Capacitor (watch to get polarity right! White stripe = -)
10	100n	C-EU050-024X044	☐ C5 ☐ C8 ☐ C9 ☐ C10 ☐ C11 ☐ C12 ☐ C13 ☐ C14 ☐ C15 ☐ C16	Electrolytic Capacitor (watch to get polarity right! White stripe = -)
1	10n	C-EU050-024X044	☐ C2	Electrolytic Capacitor (watch to get polarity right! White stripe = -)
1	1nf	C-EU050-024X044	☐ C1	Electrolytic Capacitor (watch to get polarity right! White stripe = -)
1	1nf	C-EU050-024X044	☐ C3	Styrofoam Capacitor (Styroflex)
1	47pf	C-EU050-024X044	☐ C4	Electrolytic Capacitor (watch to get polarity right! White stripe = -)
4	TL072	TL072	☐ U1 ☐ U2 ☐ U3 ☐ U4	Dual JFET Opamp
1	LM13700N	LM13700N	☐ IC1	OTA (Operational Transconductance Amplifier)
2	2N3904	2N3904	☐ Q3 ☐ Q4	NPN Transistor
1		EURO_POWER_HEADER	☐ SV1	Power Header
2	FUSE	PTC_FUSEPOLY_FUSE	☐ F1 ☐ F2	Self resetting Polyfuse (Shortcircuit Protection)
1	LM4040	LM4040	☐ SHU1	10V Voltage Reference Zener Diode Shunt
1	Pin Header	Header 10 (Female)	☐ JP1	Female 1x10 Pin Header
2	Pin Header	Header 5 (Female)	☐ JP2, JP3	Female 1x5 Pin Header
1	THAT-340	THAT-340THRUHOLE	☐ U$1	Monolithic Matched Transistors IC
1	100R	64Y-100 Trimmer	☐ V/OCT_TRIM	Precision trimmer, 25 turns, vertical
2	100k	64Y-100K Trimmer	☐ HIGH_F_TRIM ☐ SINE_ROUND_TRIM	Precision trimmer, 25 turns, vertical
1	50k	64Y-50K Trimmer	☐ SINE_SYMMETRY	Precision trimmer, 25 turns, vertical

BOM: TH-VCO1 POTS PCB [3/3]

Qty	Value	Device	Parts	Description
4	100k	Resistor 7mm	☐ R1 ☐ R4 ☐ R5 ☐ R34	Metall film resistor
1	1.8k	Resistor 7mm	☐ R33	Metall film resistor
2	1k	Resistor 7mm	☐ R14 ☐ R29	Metall film resistor
1	1M	Resistor 7mm	☐ R11	Metall film resistor
1	2M	Resistor 7mm	☐ R6	Metall film resistor
1	330k	Resistor 7mm	☐ R35	Metall film resistor
1	3k	Resistor 7mm	☐ R32	Metall film resistor
1	220nf	C-EU050-024X044	☐ C2	Electrolytic Capacitor (watch to get polarity right! White stripe = -)
1	Pin Header	Header 10 (Male)	☐ JP1	Male 1x10 Pin Header
2	Pin Header	Header 5 (Male)	☐ JP2 ☐ JP3	Male 1x10 Pin Header
5	100k	9mm Potentiometer	☐ COARSE ☐ FINE ☐ FM_LEVEL ☐ LIN_FM_LEVEL1 ☐ PULSE_WIDTH	9mm vertical snap-in pot
1	100k	9mm Potentiometer	☐ PWM_CV	9mm with plastic shaft
7	THONKICONNNEW (Thonkiconn)	WQP-PJ301M-12_JACK	☐ 1V/OCT ☐ EXP_FM ☐ LINEAR_FM ☐ PULSE_OUT ☐ PWM_INPUT ☐ SINE_OUT ☐ TRIANGLE_OUT	3.5mm jack, vertical PCB mount
7	Washers/Nuts			Washer and Nuts for Jacks
1		PFL 10		Power Cable Plug
1		PFL 16		Power Cable Plug
1		Ribbon Cable		Ribbon Cable for Power
5	Knobs Cliff	D-Shaft CL170844BR		Knobs for Potentiometer

Solder in this order to avoid trouble with part heights:

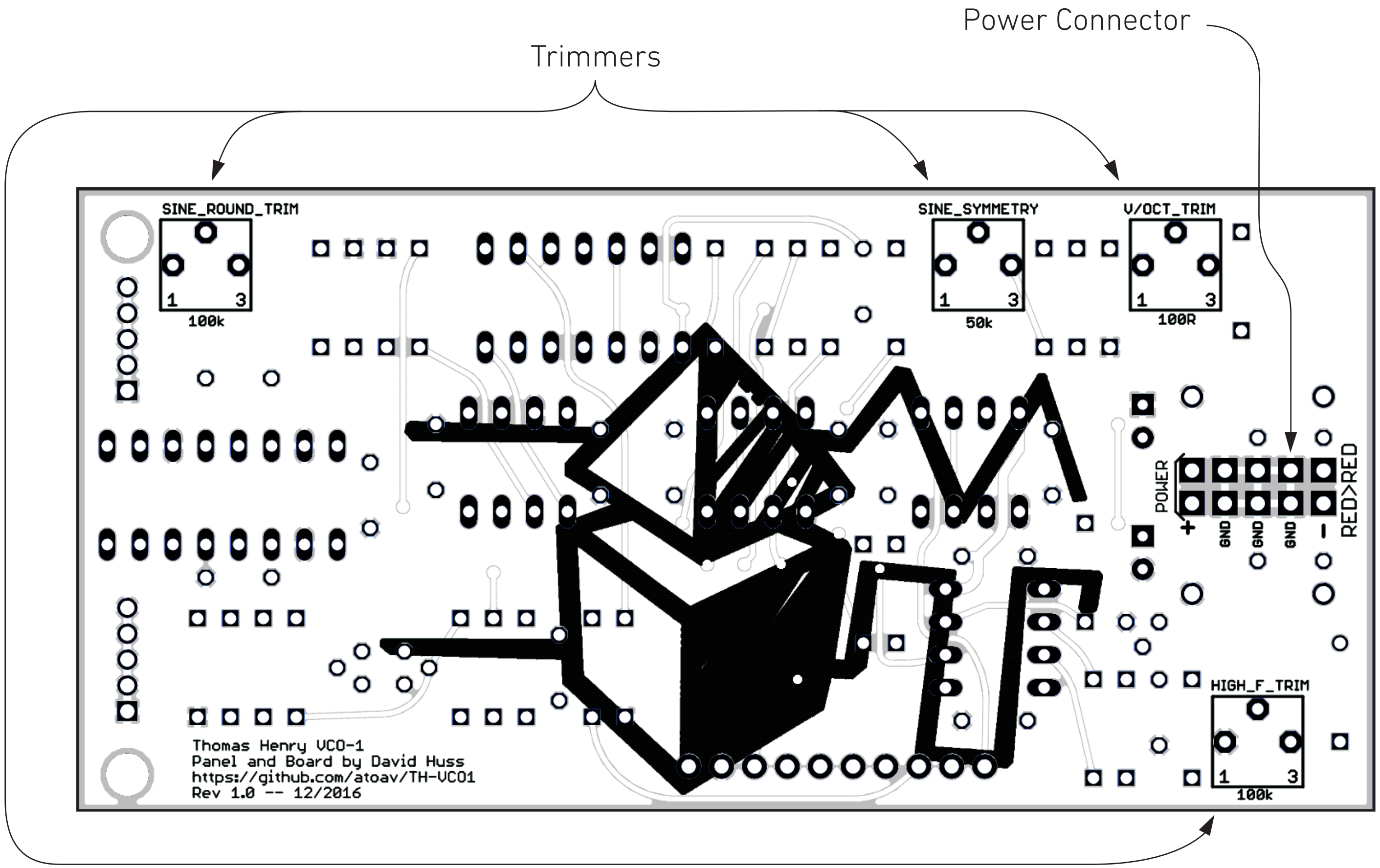
1. Solder Resistors first (R)
2. Solder Sockets for ICs
3. Solder 100n, 10n, 1n, 47p Capacitors
4. Solder 1N4001 or 1N4004 and other Diodes
5. Solder Q3 and Q4 Transistors and Polyfuses (F1, F2)
6. Solder LM4040, C6 and C7 (careful with polarity!)
7. Place Female Pin Headers (don’t solder, they shall be soldered in the end)



Turn around solderd Components PCBs:

8. Solder all 4 Trimmers

9. Solder Power Connector



Take next PCB and solder in this order:

10. Solder all Resistors first

11. Solder 220nf Capacitor

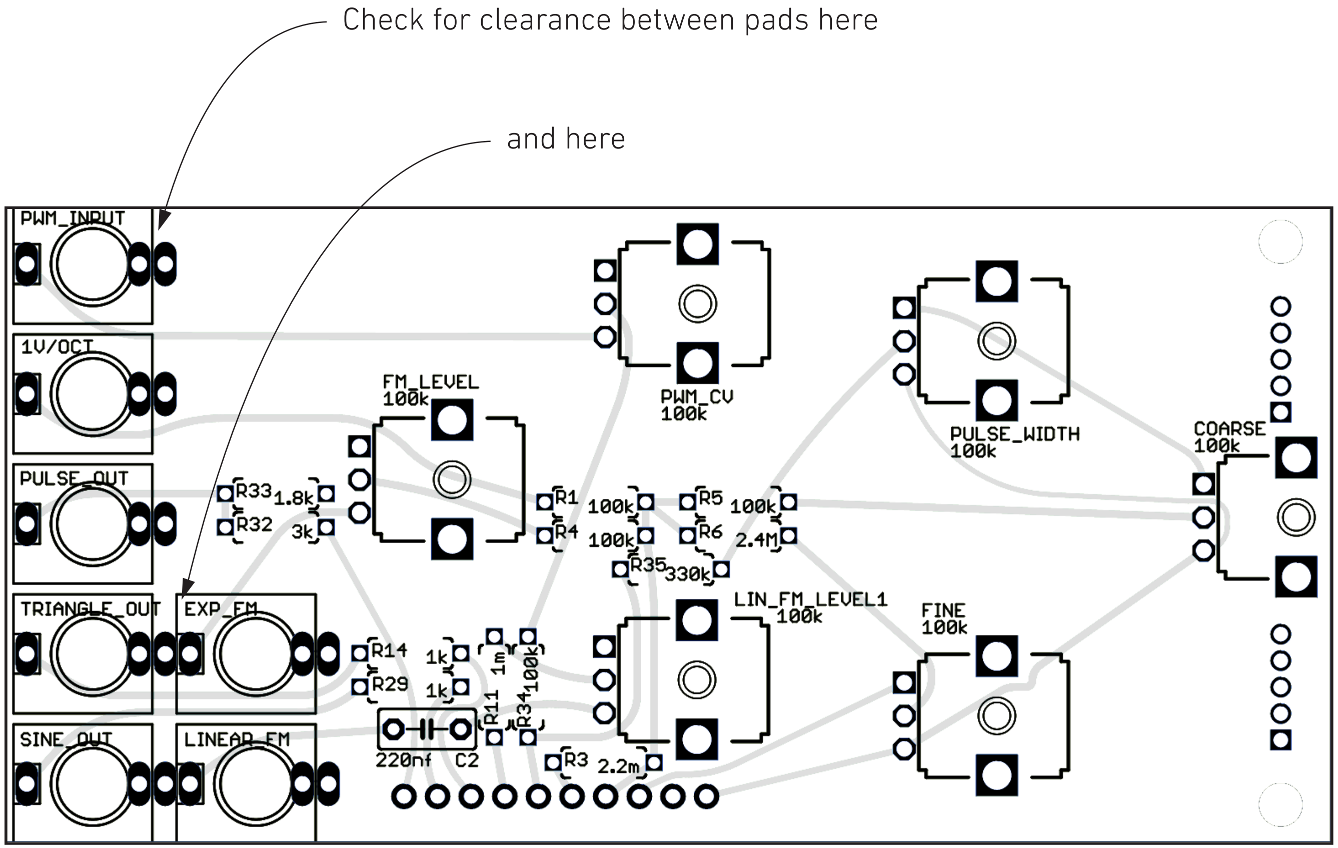
12.1 Place all Pots and Jacks into the holes (without soldering)

12.2 Fit all Pots and Jacks through the Panels. If you have a plastic shaft Pot, place it in place at the PWM_CV Pot

12.3 Put panel over pots and jacks and loosely tighten the screws with your fingers only

12.4 Solder pots and Jacks with panel in place (be extremely careful **NOT** to apply too much solder!)

12.5 Remove panel again



Turn PCB around:

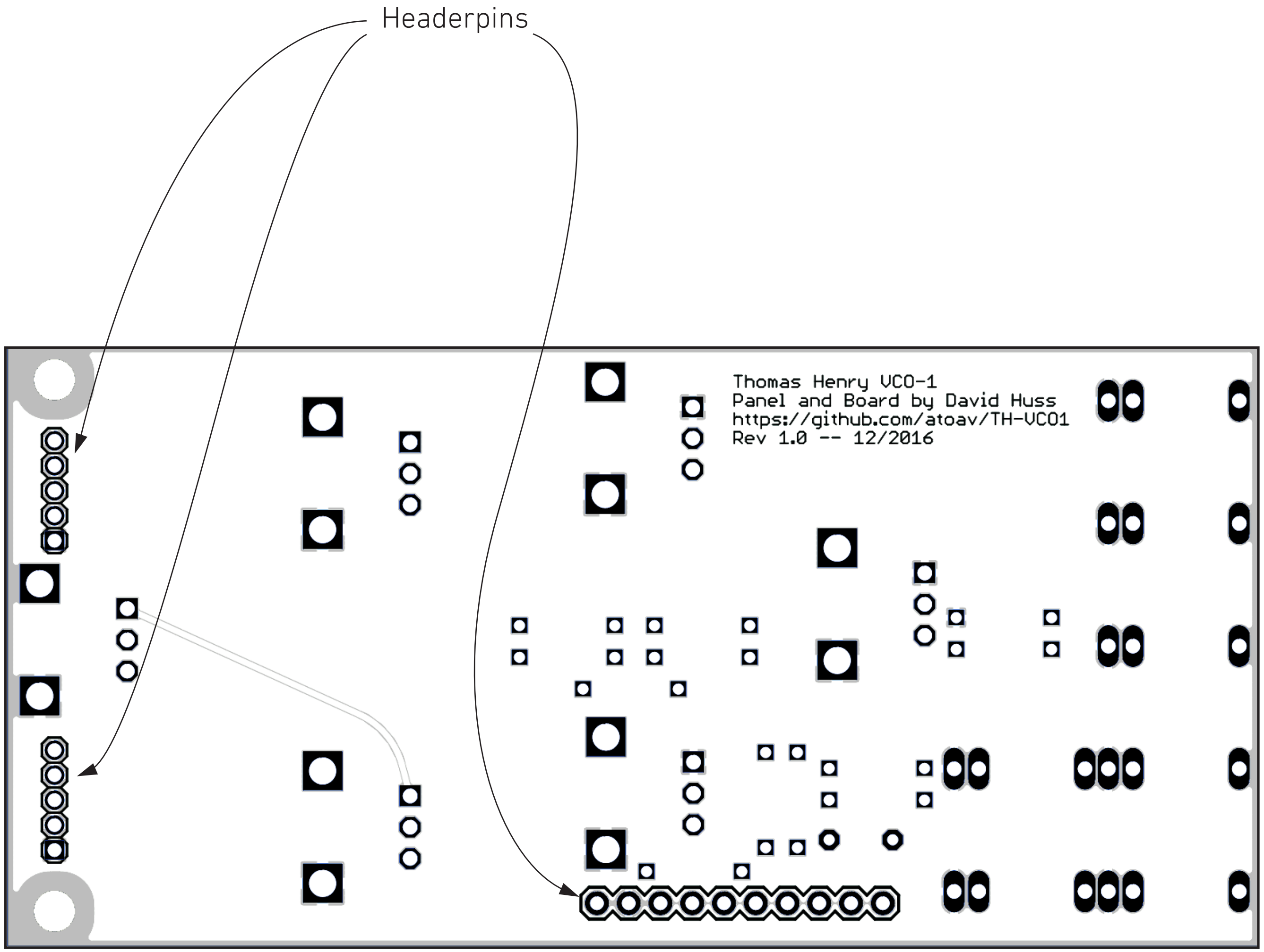
13.1 Put male Headerpins in their place (do not solder)

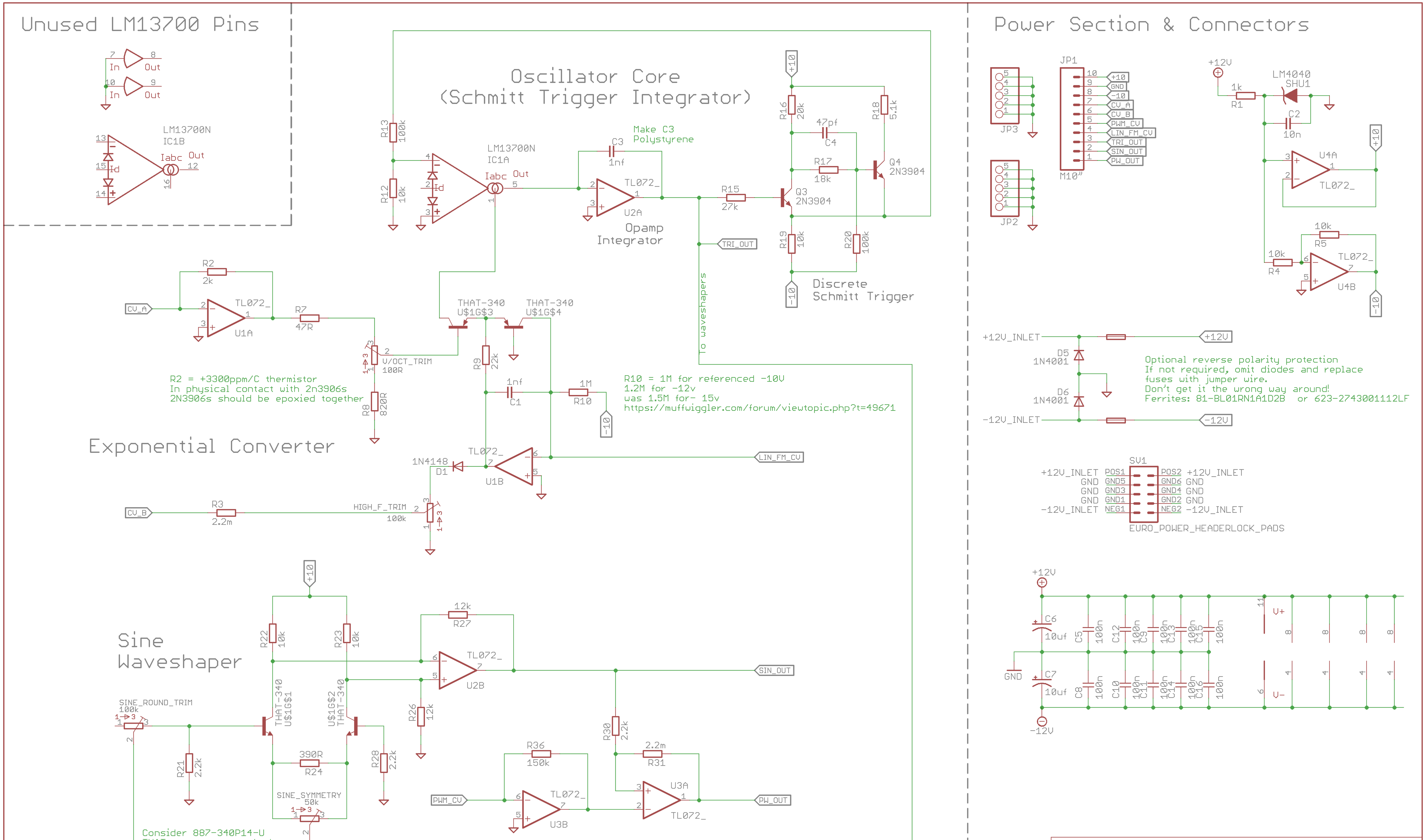
13.2 Stack Pots PCB onto Components PCB (connect male and female header pins)

13.3 With everything in place finally solder the male Headerpins to the Components PCB and the female Headerpins to the Pots PCB

14. Screw on the frontpanel and push on the knobs

15. Cut ribbon wire, make sure the connectors are placed right and press them in





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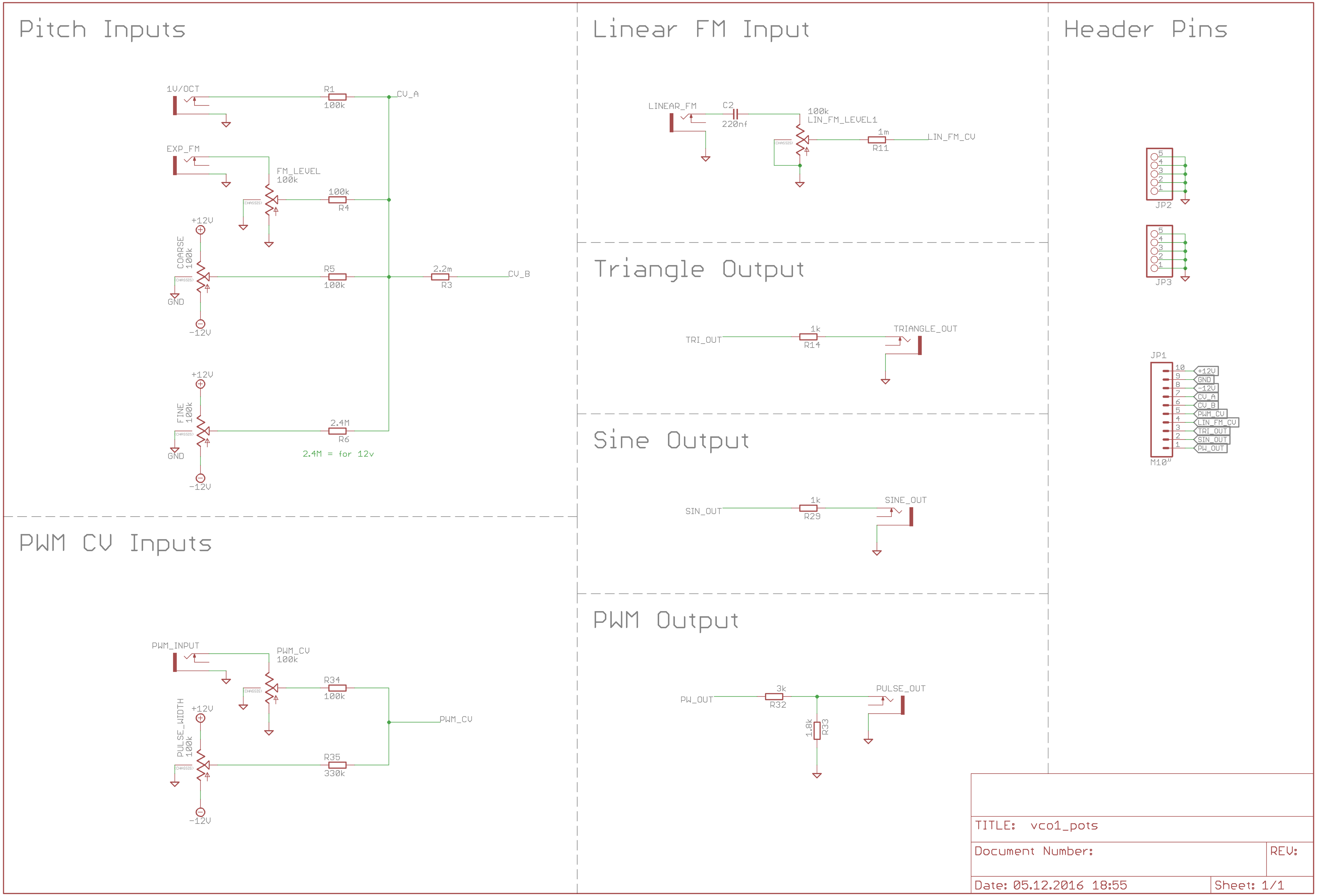

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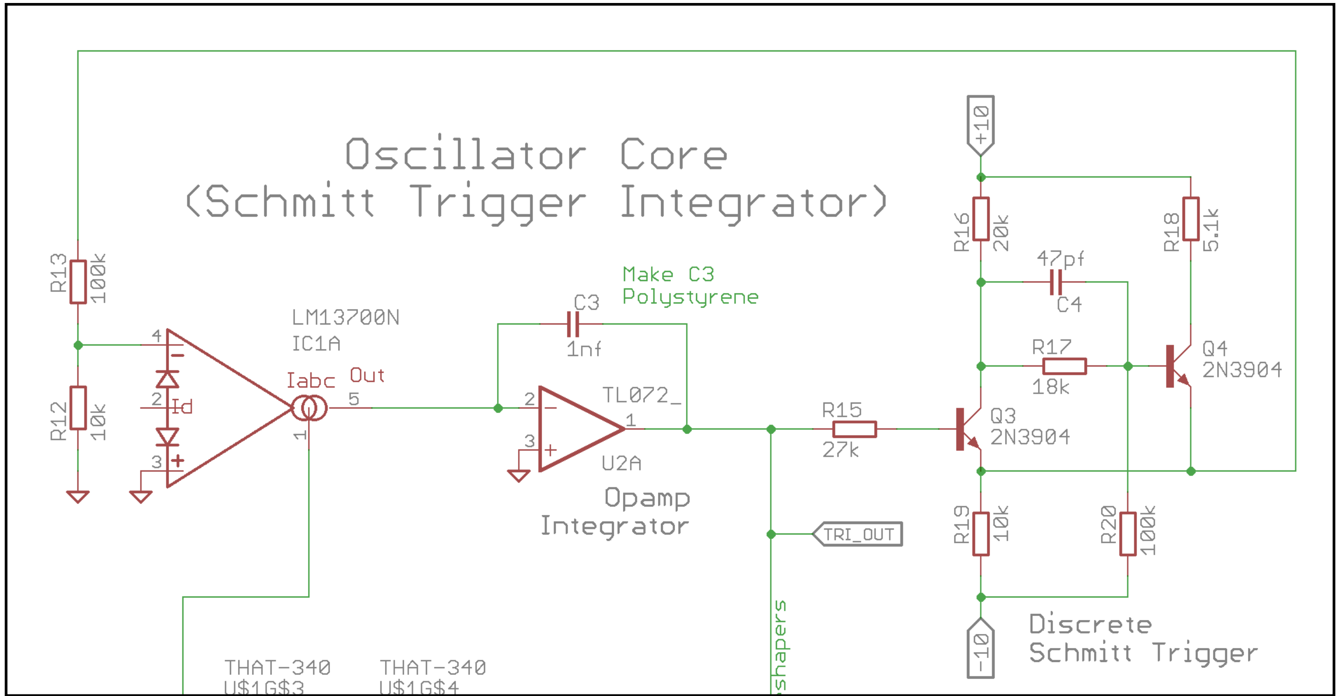
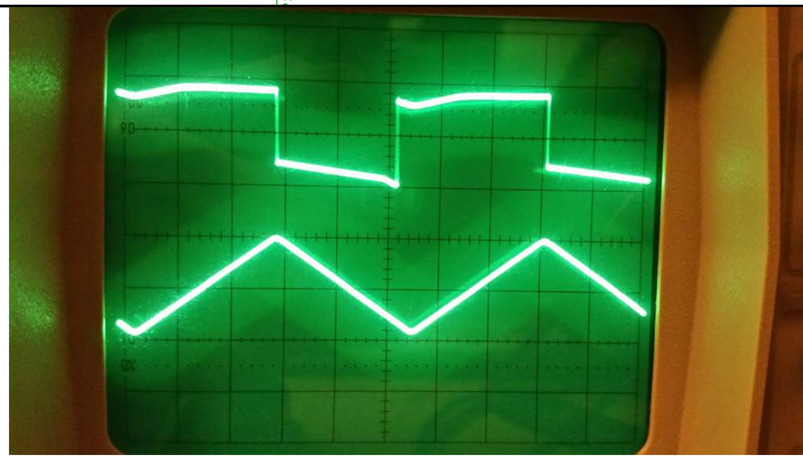
The core of the VCO-1 produces a clean triangle wave which is "shaped" into a sine from which a pulse/rectangle with variable width can be derived. The core functions by the principle of a Schmitt Trigger Integrator. This is a feedback loop between a Schmitt Trigger and an Integrator with an LM13700 OTA as a "variable resistor" to change the frequency of the oscillation.



A Schmitt Trigger is a circuit which turns an discrete input signal (=analog voltage) into a *sort-of-digital* "On-Off" voltage. The VCO-1 Schmitt Trigger (on the right side of the schematic) is a built up with two 2N3904 Transistors and switches on with a rising and off with a falling voltage (see oscilloscope traces).

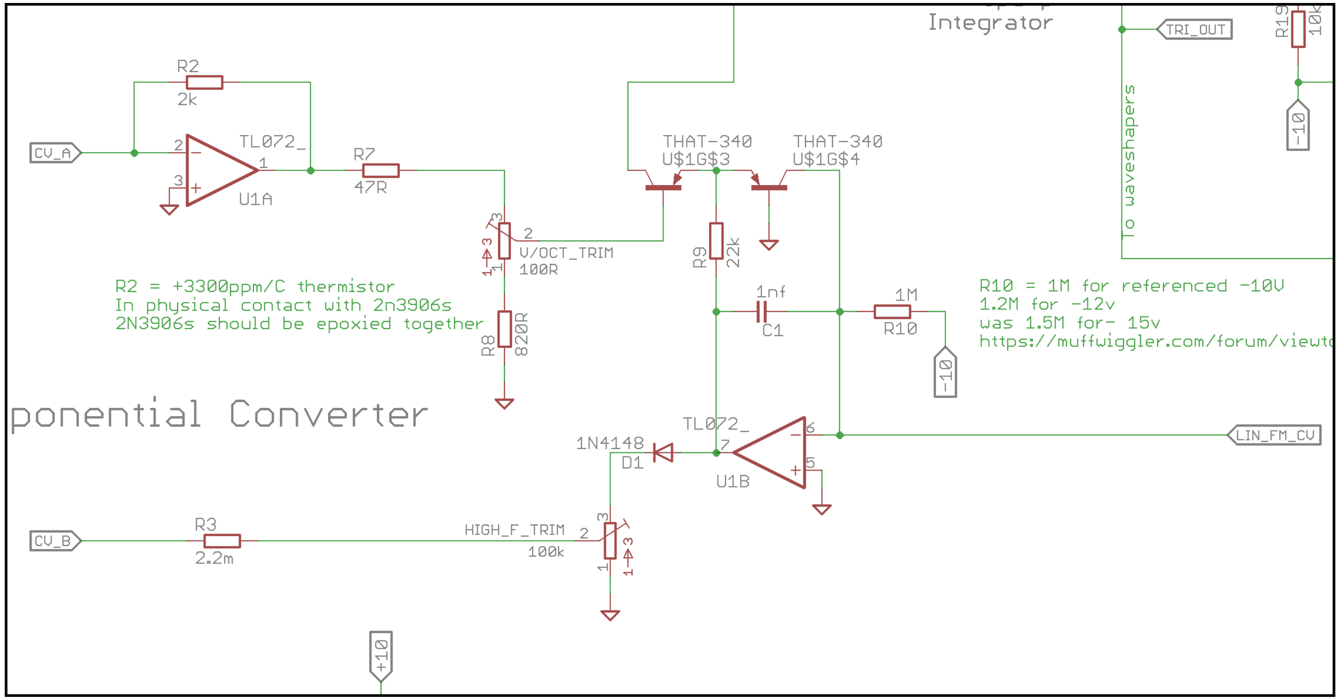


The output of this Schmitt Trigger is fed back into the Integrator (TL072 chip in the middle) via the LM13700. The Integrator integrates the current coming out of the LM13700 and creates an Triangle which is again used to feed the discrete Schmitt Trigger: a classical Feedback loop which produces a very nice and clean triangle wave.

The C3 1nF capacitor can be changed to achieve lower or higher frequencies (10nF would turn the VCO into an LFO etc.). The Schmitt Trigger could potentially be replaced with an IC or an opamp based Schmitt Trigger, however the discrete Schmitt Trigger is claimed to have superior speed (which is important to produce accurate tones at higher frequencies). In simulation this VCO achieved an output frequency up to 80kHz without any degrading of the waveforms (~20kHz is the upper limit of human hearing). Also note that the discrete Schmitt trigger is driven by stabilized ±10V from the voltage reference and not from the ±12V rails, to further improve pitch stability.

The LM13700 in the core of the VCO can be seen as a “current controlled resistor” (reality is a bit more complicated). However: if you change the current on Pin 1 of this LM13700 you change the frequency of the oscillator (and therby the pitch). The current needed for this is tiny (a few μA).

The relationship between this current and the change in frequency is by default linear. This means if we add 1V to the input voltage we also add a certain number of Hz to our frequency. But pitch is perceived exponentially. Therefore in the eurorack world we usually want to have a exponential relationship: if we add 1V the input voltage, our frequency doubles. A doubling in frequency is the step of one octave.



The schematic on this page displays the exponential converter which takes the THAT-340 monolithic NPN-PNP transistor pair as a basis. The general idea is that the collector current of a transistor is exponentially related to the input base-emitter voltage. Unfortunately, something called the emitter saturation current creates a deadly temperature sensitivity and could easily cause the unit to go way flat or sharp as things warm up or cool down – this is the reason to use two transistors. Because of the way it's been configured, the error current within the first transistor moves in the opposite direction. If the two semiconductors are closely matched in performance, then most of the temperature dependence is canceled out. Obviously a high quality pair makes a difference, and also the mechanical bonding, this is why the (sadly expensive) monolithic THAT340 is used.