Open Organ

Doctype: Schriftliche Erläuterung zur Bachelorarbeit

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1. Introduction

Open Organ is a paraphonic analog synthesizer that offers tangible connections to its circuitry. Touch-sensitive traces let the tunable voices flow through the player's fingers—or any conductive material—into the shaping section. Filter, compressor, vibrato, and mixing modules are built in. The instrument's sound is also shaped by its power input, inviting musical interaction with the power source.

The following is a supporting text detailing the composition of the instrument and the approach and values embedded in its making.

2. Modules

2.1. Tunable oscillators

The voices are implemented as relaxation oscillators[1], with each voice needing just an inverting Schmitt trigger (one sixth of a CD40106 integrated circuit[2]) and resistor-capacitor network. The inverted output is fed back to the input through a variable resistor (potentiometer), charging and discharging a capacitor to the switching voltages. The frequency of each oscillator is a function of the capacitance value, feedback resistance value, and the Schmitt trigger switching thresholds.

Modulating the power rail for the CD40106 integrated circuits has a side effect of modulating the frequency of its oscillators, since this moves the switching thresholds, affecting the time needed for the capacitors to charge/discharge to those levels.

Recognizing this as an opening for vibrato control, a suitable vibrato control voltage is generated by configuring one more tunable relaxation oscillator. The capacitor charging and discharging is smoothed through a passive low-pass filter (shape control), then scaled with another potentiometer (amount control) and summed with an offset (tune) control and buffered with an op-amp to provide enough power for the oscillators.

[1] https://en.wikipedia.org/wiki/Relaxation_oscillator
[2] https://www.ti.com/lit/ds/symlink/cd40106b.pdf

2.2. Touch mixer

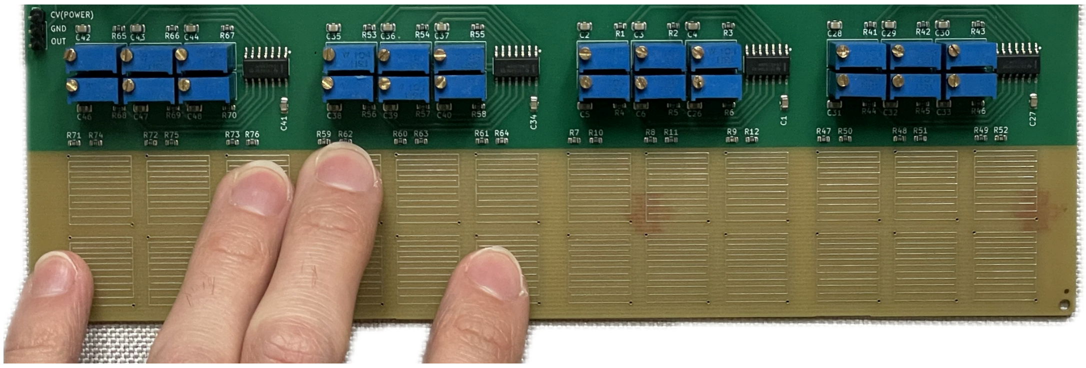

Figure: tunable oscillators (top), touch mixer (bottom)

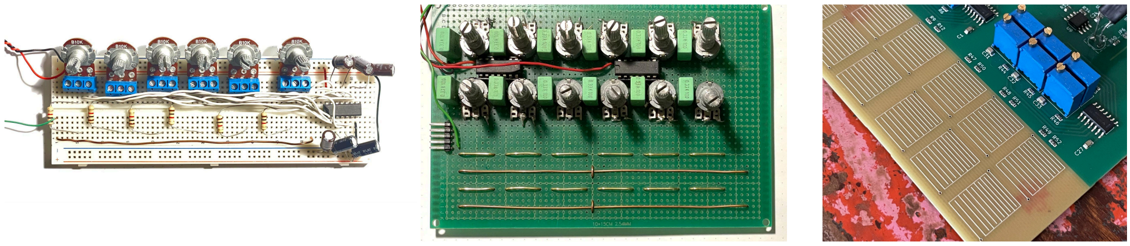

Figure: Left to right: breadboard, perfboard, printed circuit board layouts

The square waves are exposed on signal traces which are positioned next to the *mixed output* trace. By touching a finger across the signal and mixed output traces, a connection is formed through the player's skin. This makes the voice mix somewhat pressure-sensitive (as increasing the surface area in contact lowers resistance) and very moisture sensitive (sweaty hands carry the signal well). Inspecting the output with an oscilloscope reveals that the player also acts like a small capacitor between the signal and output mix, high-passing the output.

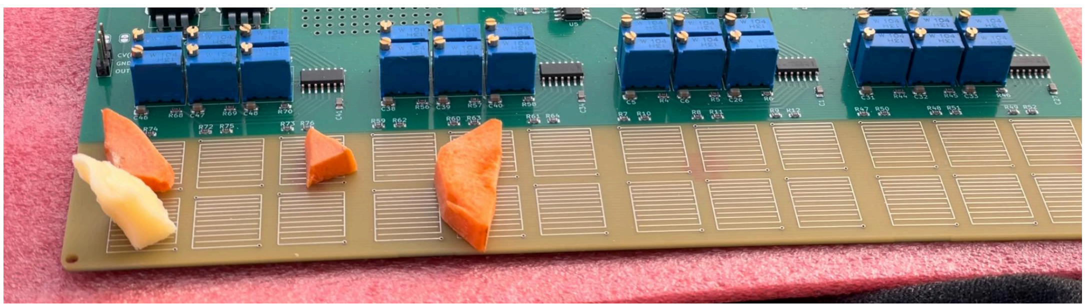

Figure: "Check the snack bag" — any conductive material can be placed across the traces to hold voices

2.3. Resonant filter

The touch-mixed voices are passed through a passive low-pass filter into an active resonant filter. A state-variable filter[3] topology is chosen for its versatility at low part count: cutoff and resonance controls and separate outputs (high-, band-, low-pass) are exposed. The cutoff frequency is set by a dual-ganged potentiometer[4]. Resonance controls from both the bandpass output and the lowpass output are exposed.

The filter outputs are buffered and mixed to the player's taste and sent to the left output.

2.4. Optical compressor/distorter

For further shaping, and in the interest of a slightly different second channel output, the buffered filter mix is also fed into a simple compression module.

The compressor is implemented as a simple amplifier with gain controlled by a photoresistor which is optically coupled to a light that is powered by the output. In this configuration, a quieter output increases the gain, and a louder output lowers the gain. The amplified signal is mixed with an adjustable offset and buffered before driving the LED. Since the photoresistor has a relatively slow response to changes in light intensity, it smooths the changes in amplification. Clipping distortion appears when the amplification amount approaches the op-amps rails.

The compressor output is buffered and sent to the right output.

2.5. Stereo output

Trim controls on the left channel (filter mix) and right channel (compressor/distortion) allow the player, with careful control, to move and shape the output in space. Suggested speaker placement: far apart and into the corners.

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[3] https://sound-au.com/articles/state-variable.htm

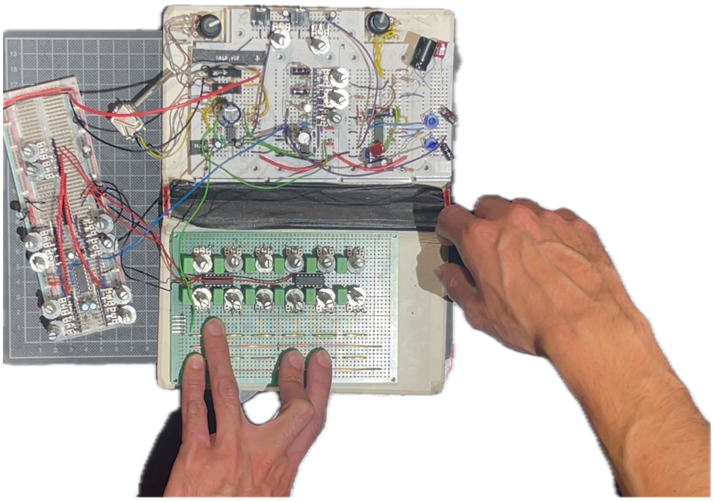
[4] In earlier iterations, I instead used vactrols (optically coupled light-emitting diode and light-dependent resistor) to expose voltage control for this parameter.

3. Compositional Approach

Some years ago, Gōnggong[5] told me, in his wonderfully thick accent, "there is old Chinese saying: 'if you drink the water, you have to think about the source.'" As looking upstream and downstream is generally a good idea for any considered act, so it seems to me that sound artists should think critically about the source of their sound, and it may do the electronic musician well to think about their circuits and power source.

So the instrument is a product of a curiosity about lower-level analog synthesis—getting closer to the source—converging with a recurring compositional approach: generating work through a process of dialog with physical systems, their quirks shaping the work in a way that is both limiting and generative (having tendencies and constraints that inform intuitions for future iterations)..

3.1. Breadboarding



The instrument emerged from meandering attempts to build a modular synthesizer on solderless breadboards[6]. These attempts were made following a simple and stubborn curiosity to make music with the building blocks of analog synthesis, embracing a process of not-knowing and learning by doing.

Breadboards, being maximally open, with every component and every connection exposed, appeal as a flexible framework to intuitively explore circuits and

[5] 公公 (maternal grandfather)

[6] https://en.wikipedia.org/wiki/Breadboard

interconnections. The breadboard experimenter can easily test changes (i.e. swap fixed values for variable control), and through monitoring, gain an understanding of the functions of the components and their interconnections. Experimenting without committing, connections made are just as easily unmade.

To place a circuit on a breadboard is to unpack it: to work one level of abstraction lower, opening the black box[7] to reveal the internal components (themselves black boxes) and their connections.

The practice of breadboarding also had an influence on design choices: being manual and somewhat tedious and error-prone[8], it motivates a restraint on parts count, but anyway this aligns with a personal preference for less: compositionally, a tendency towards slow meanders through a system, and pragmatically, a preference for lightness and portability (and less things that can go wrong).

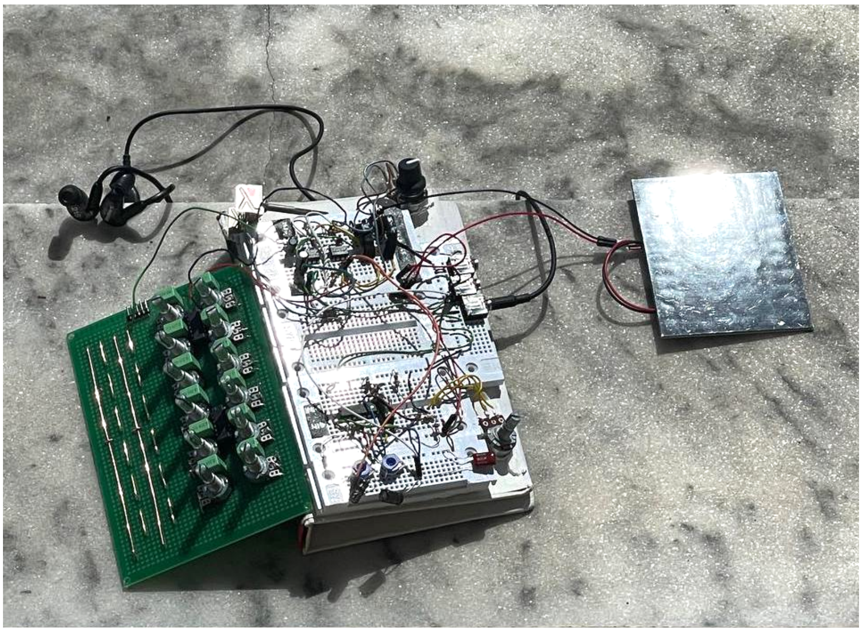


Figure: breadboard organ powered by a 6V solar panel

[7] https://en.wikipedia.org/wiki/Black_box

[8] Building circuits on breadboards is also tedious and error-prone (i.e. insert the wire one row – 2.54mm – off, and nothing is labeled anyway, now no sounds comes out…), and the solderless spring-loaded connections are not always reliable (being easy to make they are also easy to break… i.e. the wire wiggles itself loose in the backpack).

3.2. Committing

With the modules more or less settled on in a touch organ constellation, what often happened when intending to work further the instrument was just playing it. That seemed as good a sign as any for the instrument. Being decently portable already, the modules traveled with in a box and a bag, but the flipside of the breadboard's easy connections are the occasional broken connections, and after one too many troubleshooting sessions caused by unreliable connections, it was about time the design was committed to and put together in a more reliable way.

So the focus shifted from an-experiment-to-see-where-it-goes (loose breadboards great for this) to the design of a-more-reliable-portable-instrument. The design was committed to layout on a printed circuit board, opening also the potential of easy replicability.

As a first step, the patch was frozen: schematics drawn out from the status quo of the breadboards and their interconnections.

The next step was designing the board, necessitating a series of choices: on physical footprints for each of the components, how to arrange them, and how to draw connections between them. New questions arose: Which connections stay open? Surface mount (smaller and lighter) or through hole components (easier to modify)? How many layers? What trace widths?

In a familiar embrace of the not-knowing-yet-better-find-out process, a board was designed as a first test of all of these. For economic reasons and for better portability, all the modules were laid out on a single board. Anticipation of some part of the first iteration not working (as it usually happens) informed the following design choices: Connections are re-routable: traces are routed on a 2-layer board (top and bottom side) — this way they can be cut and modified if need be, not hidden inside a 4-layer board. And interconnections of the modules are routed through cuttable solder jumpers positioned next to through-hole pads at a standard spacing (0.1 inch / 2.54 mm). This way, they are default connected, but an easy possibility remains to individually test modules and to make modifications to the routing (including external connections).

Finally, perfboard-style holes were added to the empty area, keeping it open to future modifications.

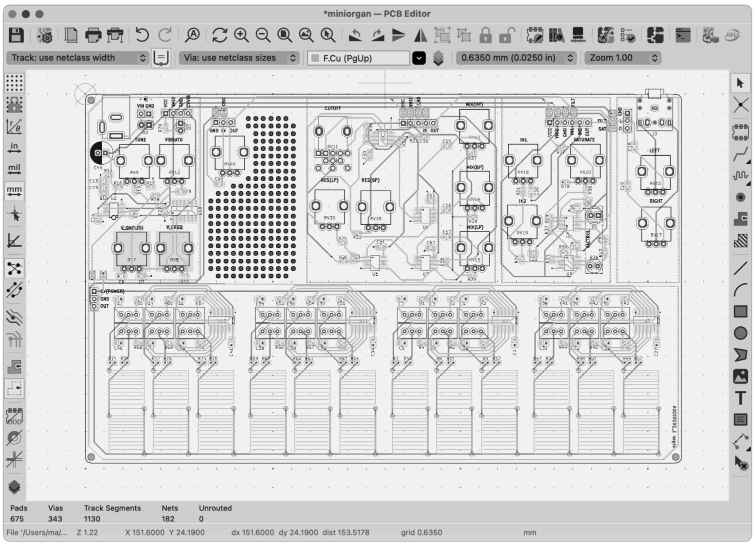


Figure: screenshot of the board layout in KiCAD

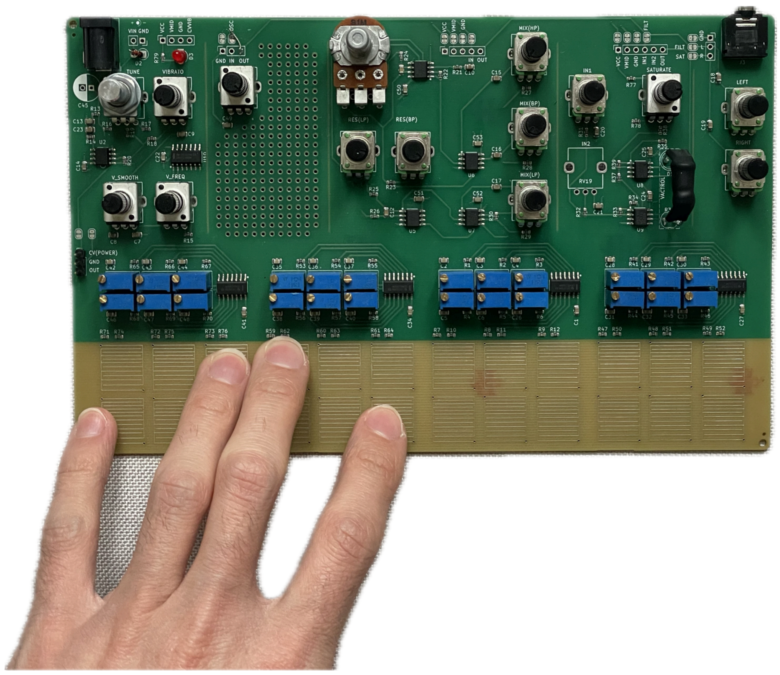


Figure: the assembled PCB

The boards arrived a week later with the surface-mount components already assembled, and I was pleased to find that after just soldering in the through hole components and fixing one routing mistake (which was easy enough thanks to the exposed interface connections) the board sounded. However, it sounded *different*. Less signal seemed to pass through the touch traces, being much thinner than than thick wires of the previous iteration's perfboard touch mixer. Another unexpected discovery was that placing the touch mixer traces in close proximity made them sensitive to humidity—the instrument responds to being breathed on! This sensitivity invites other playing techniques and performance ideas, i.e. tuning clusters that fade in and out with the performer's breath…

Figure: Open Organ played with two solar panels in series and a bread drone

4. Reflections

Open Organ remains a work in progress, but the current state is version-controlled and replicable. Next steps include refining ranges, flipping some potentiometers for more intuitive control, and fixing a small routing mistake.

The decision to use surface-mount components contributed to its compactness (and there is still room to condense further, making more room for the touch mixer) but make modifications more difficult. Future iterations could add more through-hole pads around components (at the cost of increased footprint), or add mounting sockets for easier experimentation (at the risk of unreliable solderless connections).

Committing this project to PCB, a first after many prototyped projects, was a shift toward stability—at the loss of some flexibility, but a step closer to something that feels like a finished instrument rather than a fragile experiment. Using CAD for circuit layout was a revelation: the ‘ratsnest’ tool and Design Rule Checker smoothes the transition from schematic to physical board and enables systematic iteration. And the ability to replicate designs without tedious production steps will certainly shape future work.

5. Appendix

Schematics of the first PCB version follow.