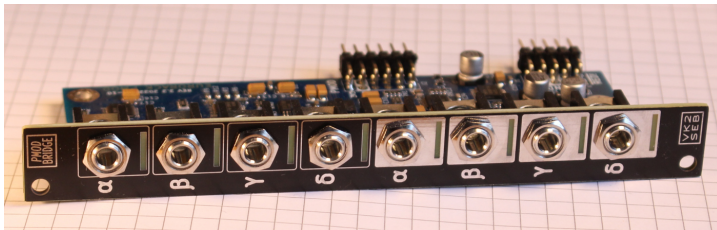
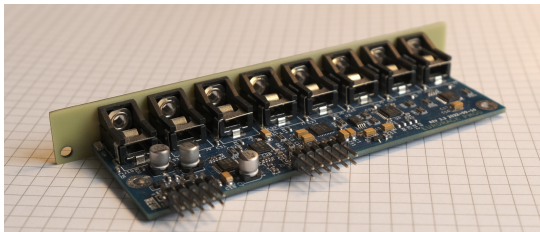


Music synthesis with FPGAs and open-source tools

`github.com/schnommus/eurorack-pmod`

me@sebholtzapfel.com





Motivation

- ▶ Easy way to get started with FPGAs & audio synthesis.
- ▶ **Eurorack**: de facto standard (modular synthesis hardware).
- ▶ **PMOD interface**: de facto standard (FPGA dev board expansion).

This project

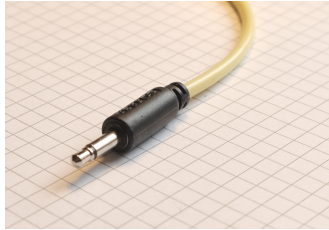
- ▶ Open hardware design for eurorack-compatible PMOD.
- ▶ Open gateway design with drivers / calibration / examples.
- ▶ Testbenches + simulation so you can play even without hardware.

What is eurorack?



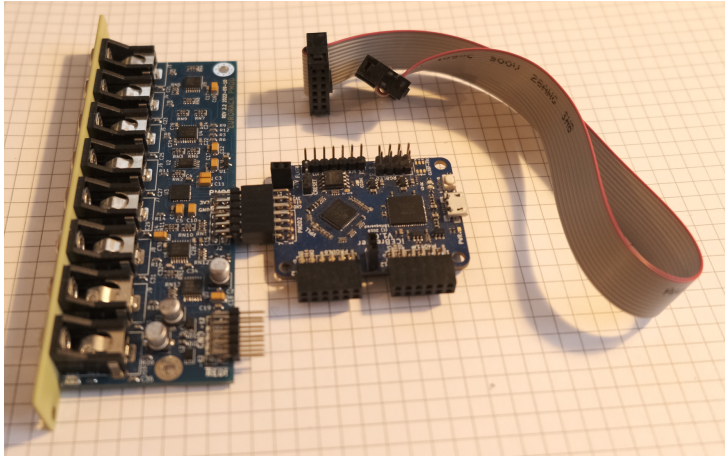
- ▶ Modular system for constructing synthesizers.
- ▶ > 15,000 modules, > 1,000 different manufacturers.

A typical module

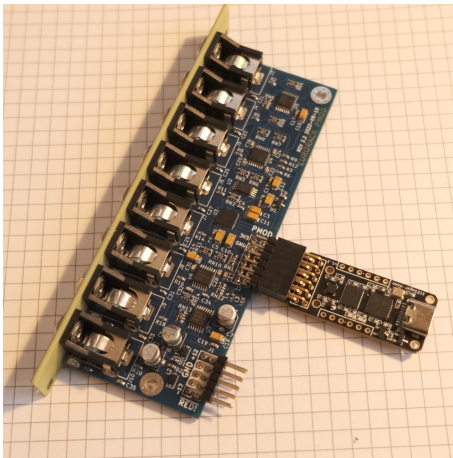


- ▶ Modules have **input** and **output** jacks.
- ▶ Maximum $\pm 10\text{V}$ signals on 3.5mm **mono jacks**

iCEBreaker (from 1BitSquared) / PMOD



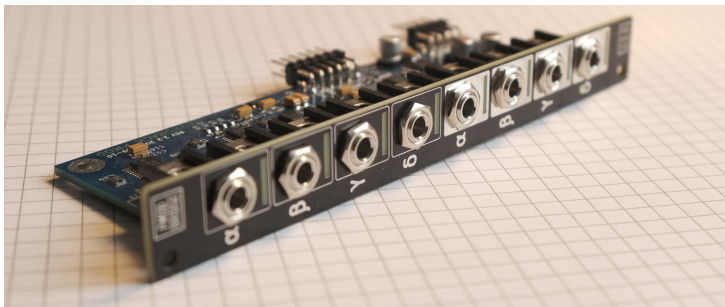
iCESugar Nano / PMOD



Demo video

- ▶ See: github.com/schnommus/fosdem23.
- ▶ File: `vid/vco-trim.mov`: eurorack-pmod acting as voltage controlled oscillator, routed through low pass filter and ADSR. Finally side-chain compressed against kick and mixed with a random granular sampler.
- ▶ File: `vid/seqsw-trim.mov`: eurorack-pmod acting as a sequential switch, randomly routing different inputs to different outputs based on a clock source. Inputs to the module are a wavetable VCO and output side-chain compressed against a kick.

What can you do with eurorack-pmod?



- ▶ Hardware, CODEC driver, calibration etc. already done.
- ▶ Start prototyping interesting logic straight away.
- ▶ Easily do things that are hard on MCU-based platforms.
 - ▶ e.g. super fast latency, tonnes of VCOs, gate-level sim of retro synth
- ▶ Even for simple things, fun playground to learn FPGAs!

Gateway examples in eurorack-pmod repository

- ▶ `vca.sv`: voltage controlled amplifier
- ▶ `vco.sv`: voltage controlled (wavetable) oscillator
- ▶ `sampler.sv`: simple .wav file sampler
- ▶ `filter.sv`: high-pass, low-pass filter
- ▶ `clkdiv.sv`: clock divider
- ▶ `seqswitch.sv`: sequential routing switch
- ▶ `bitcrush.sv`: sample bit depth reducer
- ▶ `delay.sv`: digital delay effect

Voltage-Controlled Amplifier (SystemVerilog)

```
module vca #(
    parameter W = 16
)(
    input signed [W-1:0] sample_in0,
    ...
    output signed [W-1:0] sample_out0,
    ...
);
```

```
assign sample_out0 = (sample_in0 * sample_in1) >>> W;
```

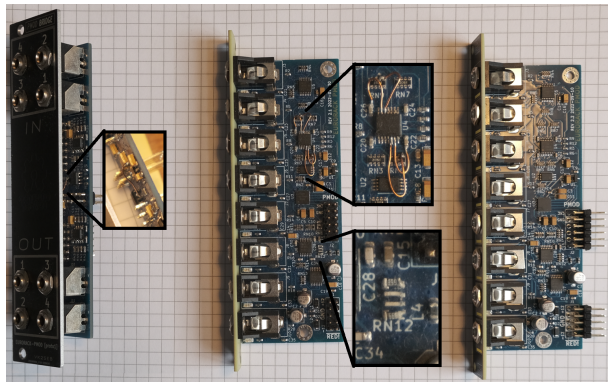
```
endmodule
```


Chasing latency



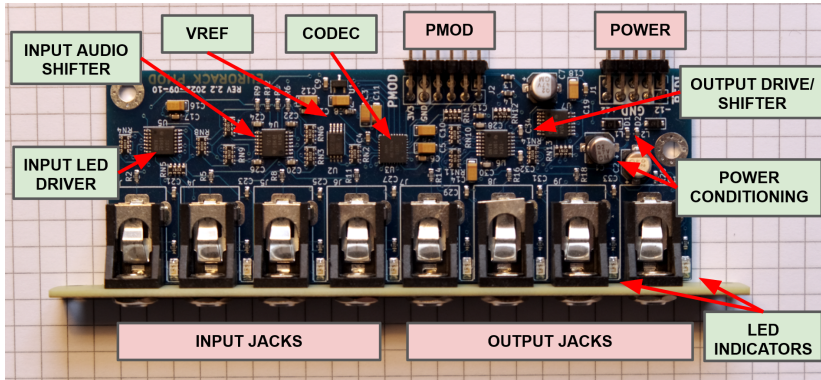
- ▶ eurorack-pmod: about 120uS latency (24 samples @ 192KHz)
 - ▶ Likely internal CODEC filter or DAC/ADC pipelining.
- ▶ also pictured: disting mk3 (digital precision adder)

Hardware evolution



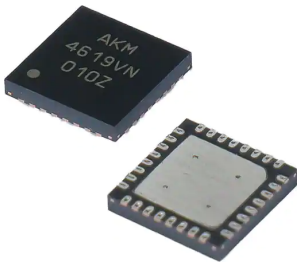
- ▶ KiCAD files available on GitHub.
- ▶ Rev. 2.2 works without any bodes.

Hardware overview



- ▶ 4HP eurorack-compatible module with PMOD interface.
- ▶ 8 (4 in + 4 out) DC-coupled channels with LED indicators.
- ▶ 192KHz / 32bit sampling on all channels.

Deeper - Audio CODEC

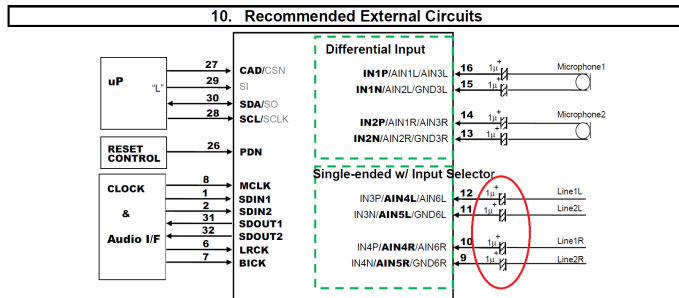


AK4619VN audio codec IC

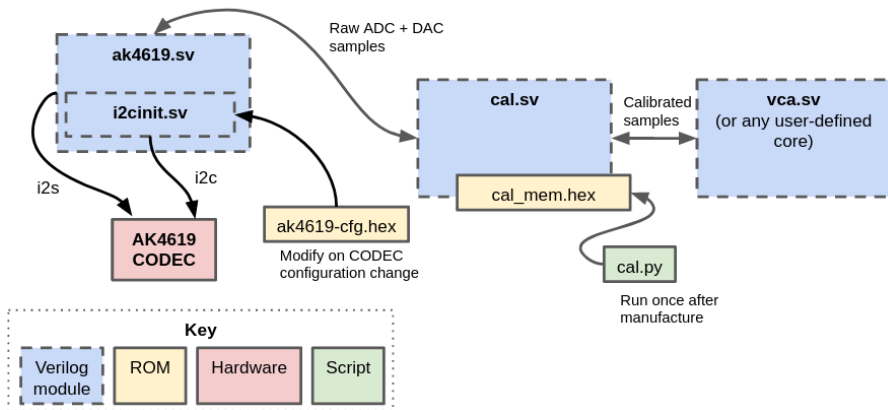
- ▶ All 8 channels on a single I2S-like interface (fits in 1x PMOD)
- ▶ Much cheaper than instrumentation-quality ADCs/DACs (\$3/unit)
- ▶ **Can be misused in a DC-coupled mode, if calibration used**

DC coupling and calibration

- ▶ Ignore recommended input/output topology from datasheet
- ▶ Disable all digital high-pass filters in CODEC registers
- ▶ Calibrate DC extents at $\pm 5V$, linear regression
- ▶ Calibrate all samples online in FPGA gateway



Gateway architecture

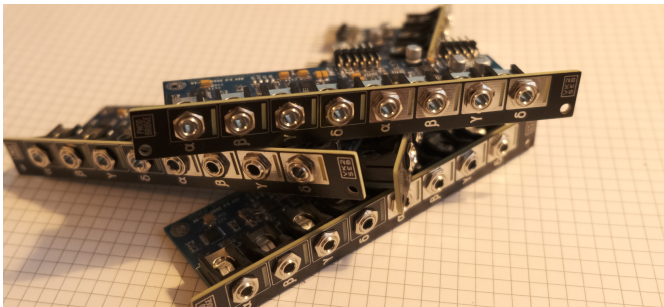


No hardware? - VCVRack



- ▶ VCV Rack plugin to **simulate verilog on a eurorack-pmod module**.
- ▶ github.com/schnommus/verilog-vcvrack

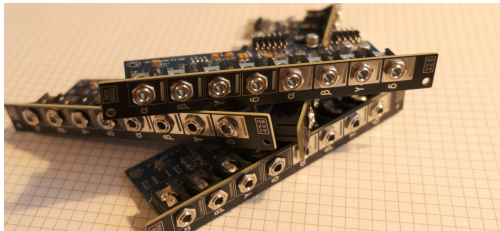
Manufacturing



Revision 3 hardware

- ▶ Jack insertion detection
- ▶ Calibration memory on board
- ▶ Leds controllable by FPGA directly
- ▶ Cheaper to manufacture & lower profile

Thank you for listening!

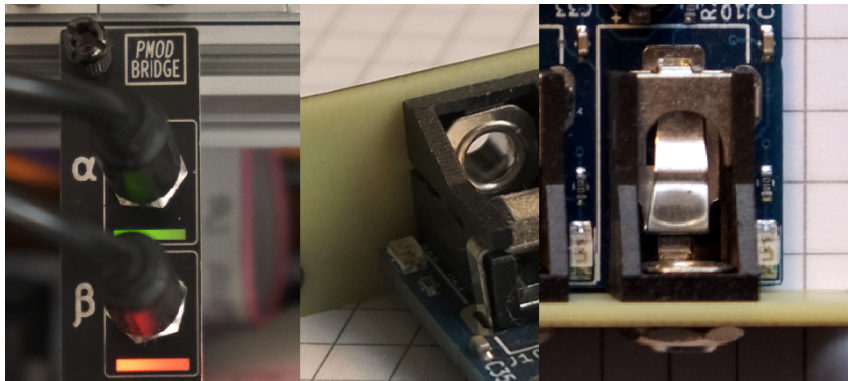


- ▶ contact: me@sebholzapfel.com
- ▶ github.com/schnommus/eurorack-pmod
- ▶ github.com/schnommus/verilog-vcvrack

Help! Should I do a manufacturing run?

- ▶ Star the GitHub repository
- ▶ Sign up in 'Manufacturing' section of README.md

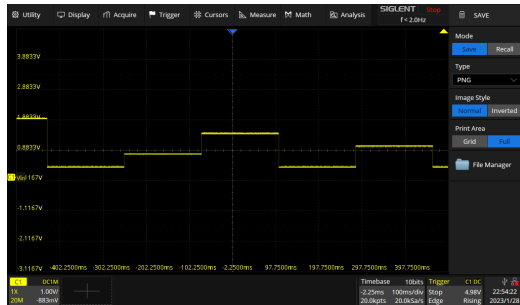
Backup: Light bleed through PCB



Backup: Signals in Eurorack

Control Voltages

- ▶ Generally lower frequency (roughly $< 1\text{kHz}$)
- ▶ DC absolute accuracy is important (1V/oct)
- ▶ **example:** drum trigger, oscillator pitch



Backup: Signals in Eurorack

Audio Signals

- ▶ Generally higher frequency
- ▶ Absolute accuracy not so important
- ▶ **example:** echo or distortion effect.

