# PROGNOSTICATOR-6

A feature-rich synthesizer with an exceptional user experience

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# Problem Statement

Analog Synthesizer

- Manipulation
  - Akin to an acoustic instrument
- Features
  - Expensive to implement
- Sound Quality
  - It sounds better! (maybe)

Digital Synthesizer

- Manipulation
  - Lives in a world of software
- Features
  - Simpler implementation
- Sound Quality
  - Imitation will never be the real thing

Conclusion: Hybrid Synthesizer!

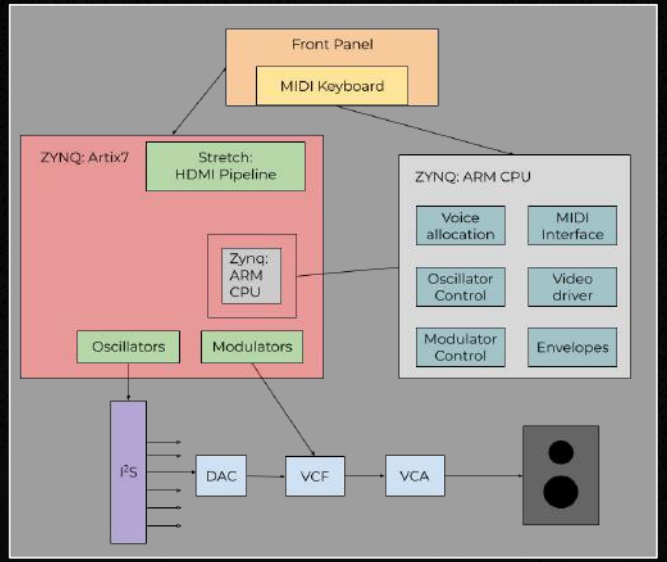
# Use-Case Requirements

| |
|---|
| Polyphony or Paraphony |
| Wavetables (wave synthesis) |
| Oscillators (2 per voice) |
| Tunable Analog Filters (LPF Amp, resonance) |
| Effects (pitch shifting, chords, arpeggiators) |
| Front Panel (rotary encoders, stretch: display) |
| Robust Enclosure (aluminium and/or wood) |

| |
|---|
| Pitch Correctness (±3¢) |
| Filter Cutoff (<5% off ideal) |
| THD (<1%) |
| Competitive Pricing (<$400) |
| User Enjoyment (>70% +ve feedback) |
| Portability ( >= toaster, < microwave) |

# Approach - ***recap***

- Physical
  - MIDI keyboard - purchased
  - Front panel - encoders, potentiometers, buttons
- FPGA (PYNQ Z2)
  - Wavetables?
  - SoC handles many effects
- $I^2S$ Audio DAC
  - DAC output to analog filter
- Analog Filters and Amplifier
  - Voltage controlled cutoff
  - Voltage controlled resonance
  - Reduced scope to only include LPF

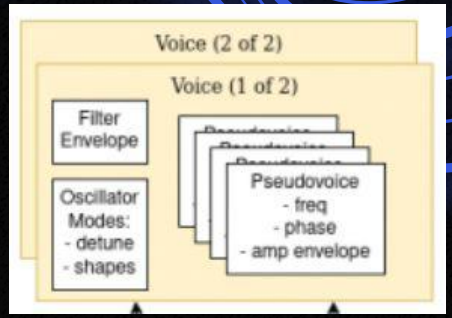


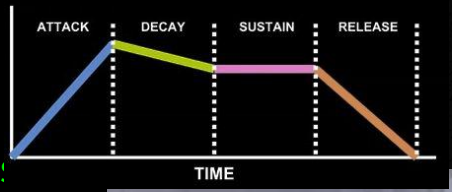
# Tradeoff:
# **Paraphonic vs Polyphonic**

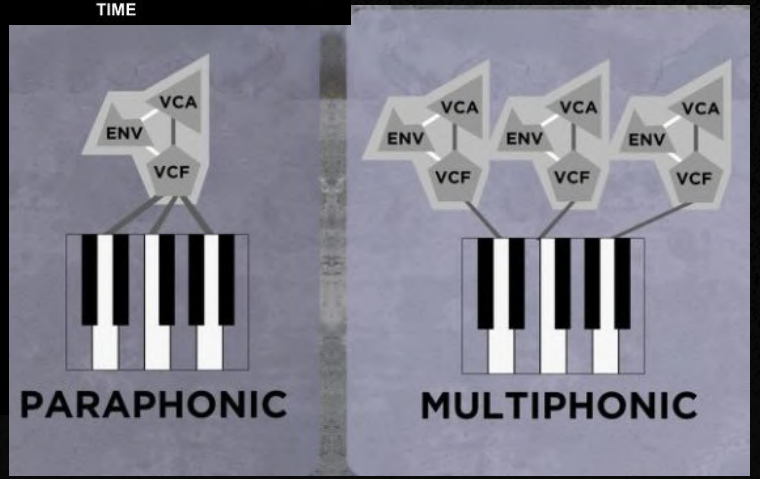
Paraphonic:
- Simple Circuit Design
- Single Filter Envelope, mono output

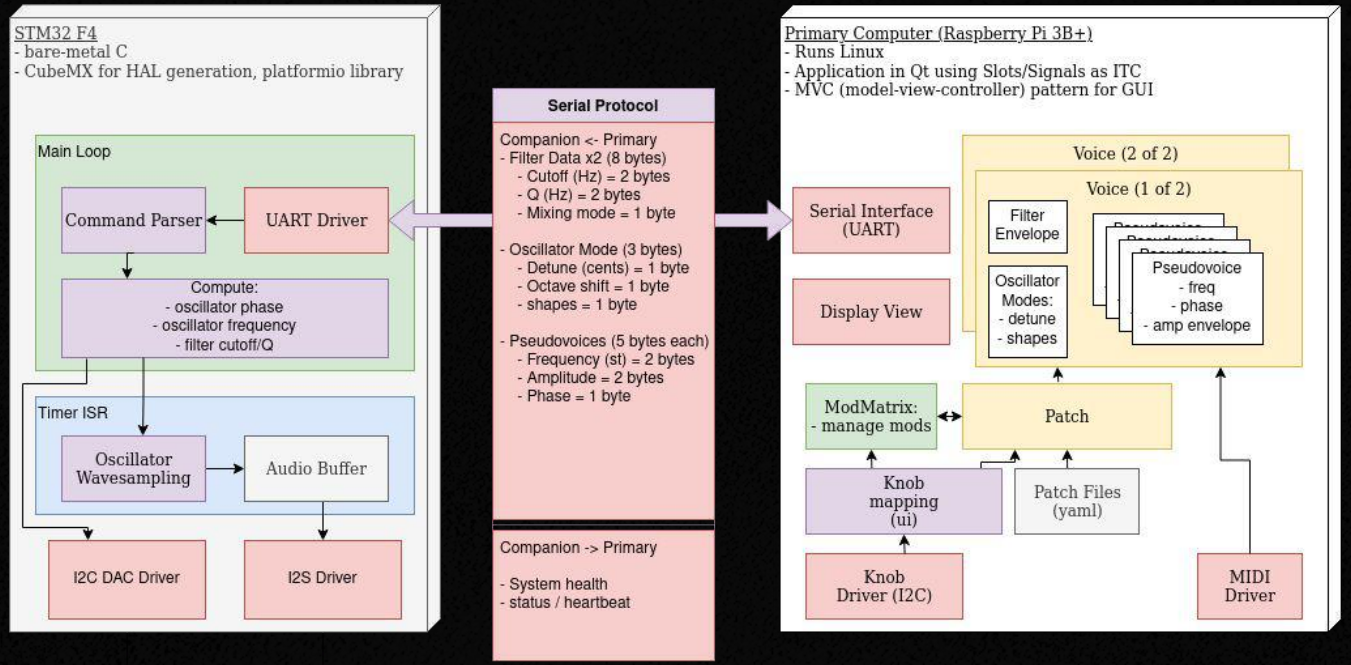
Polyphonic:
- Many (6+) Filter envelopes
- Accurate for stringed instruments
- “Large” spectral complexity
- Complex implementation

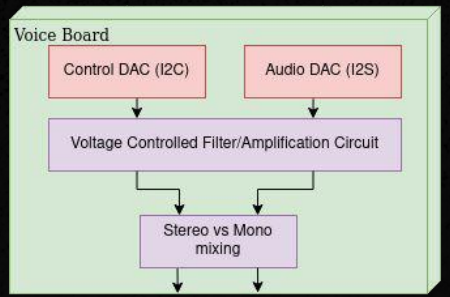
**Compromise: Duophonic!**
- Dual Filter Envelope
- Stereo output
- Simple Circuit Design





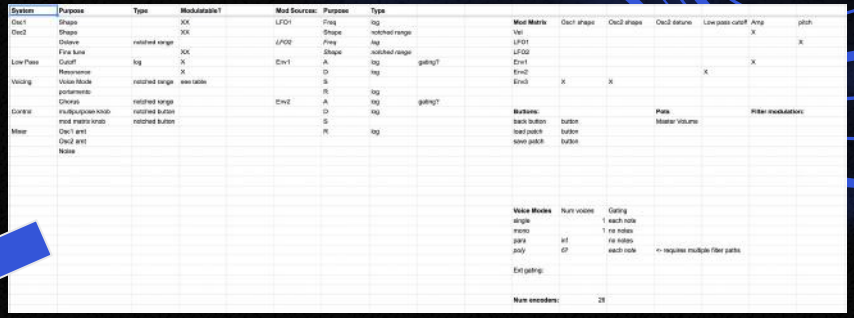




# Complete Solution - *changes*:

- Zynq -> **Raspberry Pi + stm32 MCU**
- **Wavetables** are out of scope
- **Duophonic** synthesizer (2 hardware voices)

# Solution: UI Design / Case

- Continued from knob design sheet
- Finalized laser etching / sheet metal

| System | Purpose | Type | Modulatable? | Mod Sources: | Purpose | Type | | Mod Matrix | Osc1 shape | Osc2 shape | Osc2 detune | Low pass cutoff | Amp | pitch |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Osc1 | Shape | | XX | LFO1 | Freq | log | | Vel | | | | | X | |
| Osc2 | Shape | | XX | | Shape | notched range | | LFO1 | | | | | | X |
| | Octave | notched range | | LFO2 | Freq | log | | LFO2 | | | | | | |
| | Fine tune | | XX | | Shape | notched range | | Env1 | | | | | X | |
| Low Pass | Cutoff | log | X | Env1 | A | log | gating? | Env2 | | | | X | | |
| | Resonance | | X | | D | log | | Env3 | X | X | | | | |
| Voicing | Voice Mode | notched range | see table | | S | | | | | | | | | |
| | portamento | | | | R | log | | **Buttons:** | | | **Pots** | | **Filter modulation:** | |
| | Chorus | notched range | | Env2 | A | log | gating? | back button | button | | Master Volume | | | |
| Control | multipurpose knob | notched button | | | D | log | | load patch | button | | | | | |
| | mod matrix knob | notched button | | | S | | | save patch | button | | | | | |
| Mixer | Osc1 amt | | | | R | log | | | | | | | | |
| | Osc2 amt | | | | | | | | | | | | | |
| | Noise | | | | | | | | | | | | | |

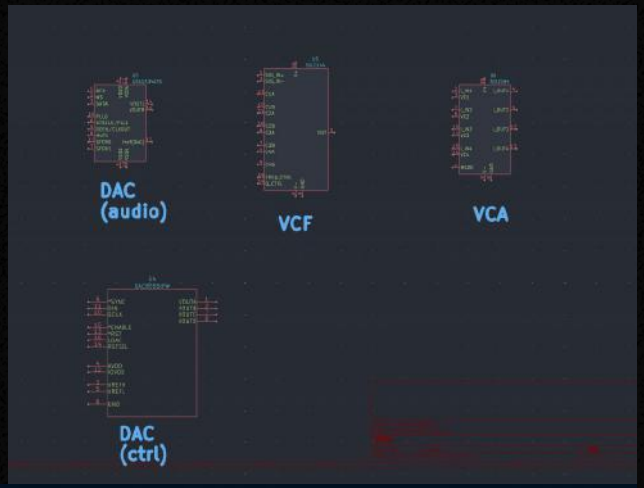
| **Voice Modes** | Num voices | Gating | |
|---|---|---|---|
| single | 1 | each note | |
| mono | 1 | no notes | |
| pairs | inf | no notes | |
| poly | 07 | each note | <- requires multiple filter parts |

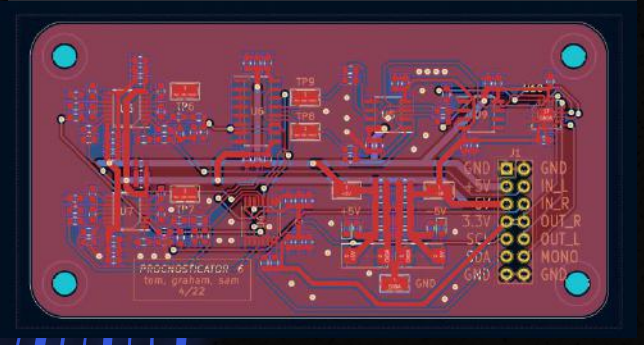
Ext gating:

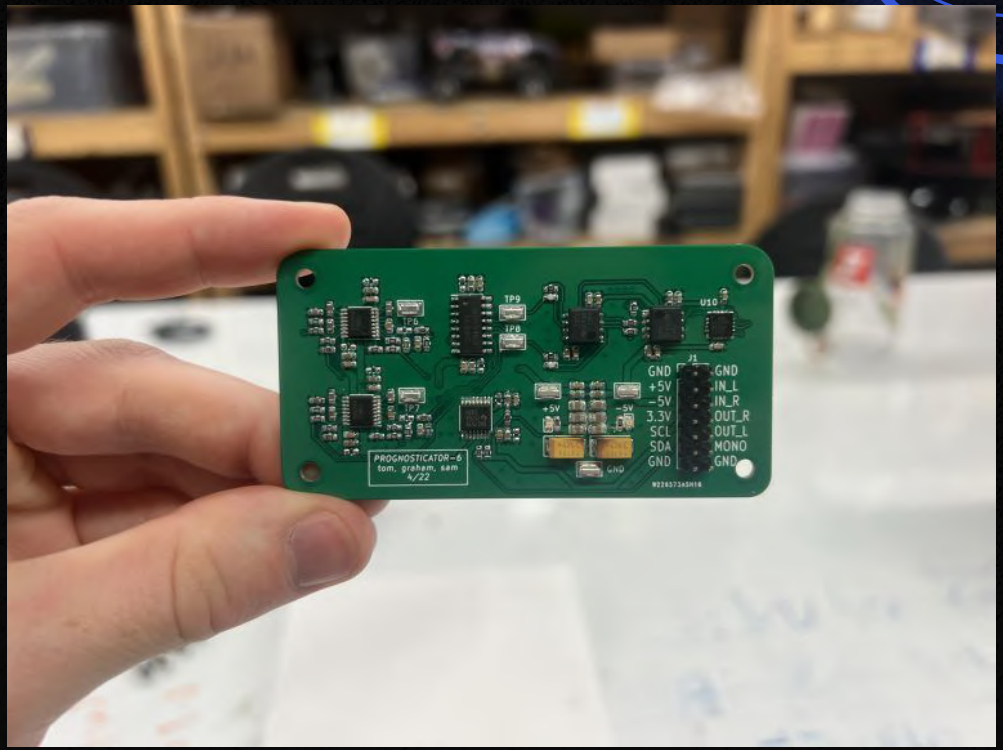
**Num encoders:** 28

# Solution: Filter Design

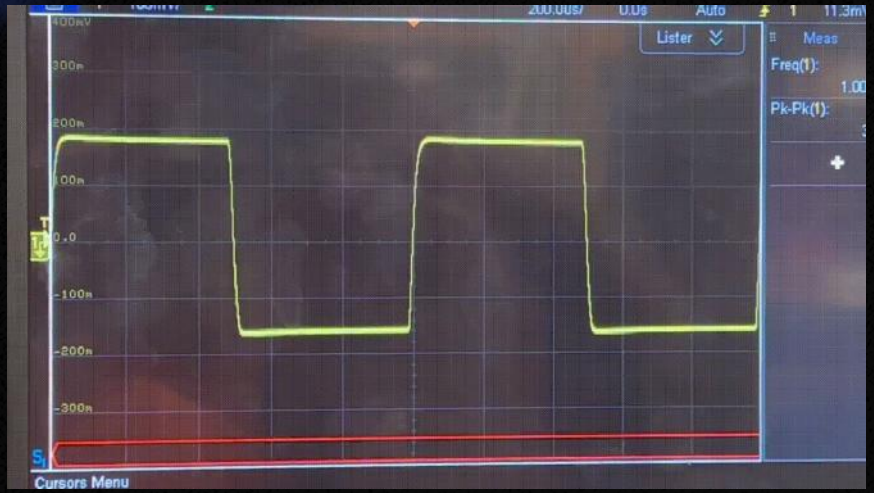
- Fabricated and tested filter circuits with monolithic ICs



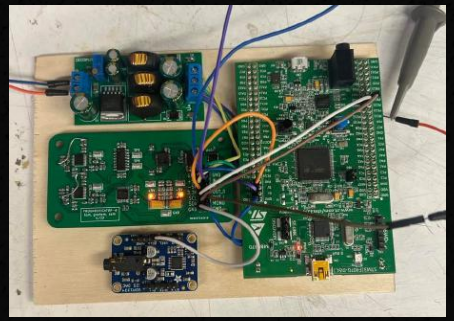
# Testing/Verification: Requirements




| |
|---|
| THD (<1%) -> 0.58%* |
| Noise (inaudible) -> 8.9mV pk-pk = -27.0dB |
| Channel Matching: (2.5%) -> 1.43%** |
| Filter Flatness: (-10dB) -19dB peak** |
| Pitch Correctness (±3¢) -> **TODO** |
| Filter Cutoff (<5% off ideal) -> ***TODO*** |
| User Enjoyment (>70% feedback) -> ***TODO*** |
| Latency (5ms) -> ***TODO:*** Architecture supports |

Methodology:

- Sweep
  - Filter cutoff
  - Filter Q
  - Input Frequency
- Noise measurements

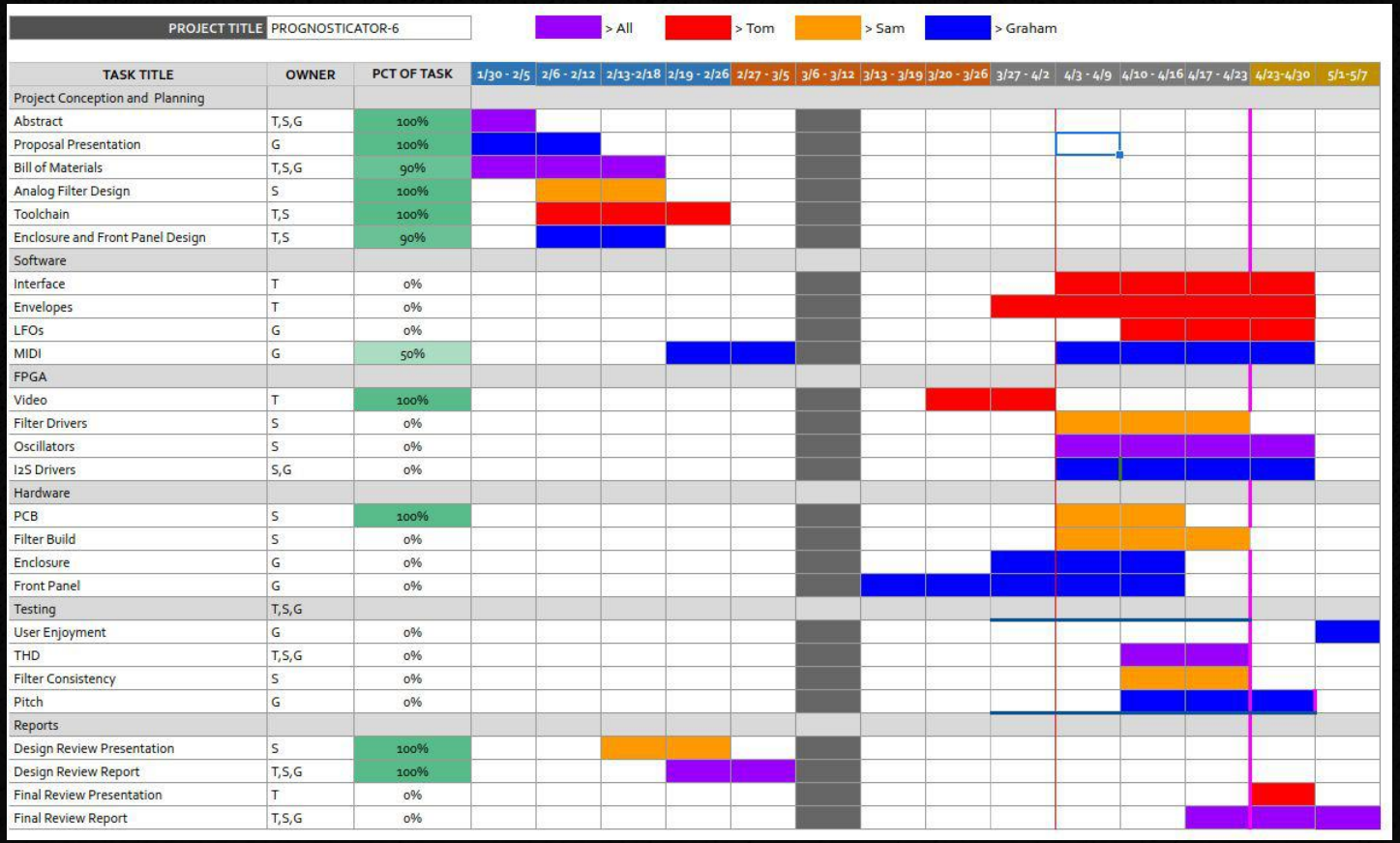


*Improved measurement requires better instrumentation equipment
**This can be improved with calibration steps

# Testing/Verification: Feature Recap

| |
|---|
| Polyphony or Paraphony -> Paraphony: HW done, SW in progress |
| Wavetables (wave synthesis) -> Not planned |
| Oscillators (2 per voice) -> Pseudovoices in progress |
| Tunable Analog Filters (LPF Amp, resonance) -> Pass requirements |
| Effects (pitch shifting, chords, arpeggiators) -> Implementing |
| Front Panel (rotary encoders, stretch: display) -> Fabricated, GUI in progress |
| Robust Enclosure (aluminium and/or wood) -> Fabricated |

# Gantt Chart / Progress




| TASK TITLE | OWNER | PCT OF TASK | 1/30 - 2/5 | 2/6 - 2/12 | 2/13-2/18 | 2/19 - 2/26 | 2/27 - 3/5 | 3/6 - 3/12 | 3/13 - 3/19 | 3/20 - 3/26 | 3/27 - 4/2 | 4/3 - 4/9 | 4/10 - 4/16 | 4/17 - 4/23 | 4/23-4/30 | 5/1-5/7 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Project Conception and Planning | | | | | | | | | | | | | | | | |
| Abstract | T,S,G | 100% | | | | | | | | | | | | | | |
| Proposal Presentation | G | 100% | | | | | | | | | | | | | | |
| Bill of Materials | T,S,G | 90% | | | | | | | | | | | | | | |
| Analog Filter Design | S | 100% | | | | | | | | | | | | | | |
| Toolchain | T,S | 100% | | | | | | | | | | | | | | |
| Enclosure and Front Panel Design | T,S | 90% | | | | | | | | | | | | | | |
| Software | | | | | | | | | | | | | | | | |
| Interface | T | 0% | | | | | | | | | | | | | | |
| Envelopes | T | 0% | | | | | | | | | | | | | | |
| LFOs | G | 0% | | | | | | | | | | | | | | |
| MIDI | G | 50% | | | | | | | | | | | | | | |
| FPGA | | | | | | | | | | | | | | | | |
| Video | T | 100% | | | | | | | | | | | | | | |
| Filter Drivers | S | 0% | | | | | | | | | | | | | | |
| Oscillators | S | 0% | | | | | | | | | | | | | | |
| I2S Drivers | S,G | 0% | | | | | | | | | | | | | | |
| Hardware | | | | | | | | | | | | | | | | |
| PCB | S | 100% | | | | | | | | | | | | | | |
| Filter Build | S | 0% | | | | | | | | | | | | | | |
| Enclosure | G | 0% | | | | | | | | | | | | | | |
| Front Panel | G | 0% | | | | | | | | | | | | | | |
| Testing | T,S,G | | | | | | | | | | | | | | | |
| User Enjoyment | G | 0% | | | | | | | | | | | | | | |
| THD | T,S,G | 0% | | | | | | | | | | | | | | |
| Filter Consistency | S | 0% | | | | | | | | | | | | | | |
| Pitch | G | 0% | | | | | | | | | | | | | | |
| Reports | | | | | | | | | | | | | | | | |
| Design Review Presentation | S | 100% | | | | | | | | | | | | | | |
| Design Review Report | T,S,G | 100% | | | | | | | | | | | | | | |
| Final Review Presentation | T | 0% | | | | | | | | | | | | | | |
| Final Review Report | T,S,G | 0% | | | | | | | | | | | | | | |

# Conclusion

- Our hope
  - Build a solid basic synthesizer with a focus on enjoyment, good design, and good sound.
  - Implement as many supplementary features as possible
- Lessons
  - Focus on simple toolchains, accessible platforms.
- Big TODOs for us:
  - Final construction
  - Lots of software