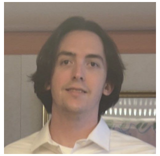
Cost-effective Hardware Oriented Real-time Digital Synthesizer

C.H.O.R.D.S.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Senior Design Project Proposal

Sonoma State University Department of Engineering Science

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Date 12/6/2024

Website: https://chordsynthesizer.com

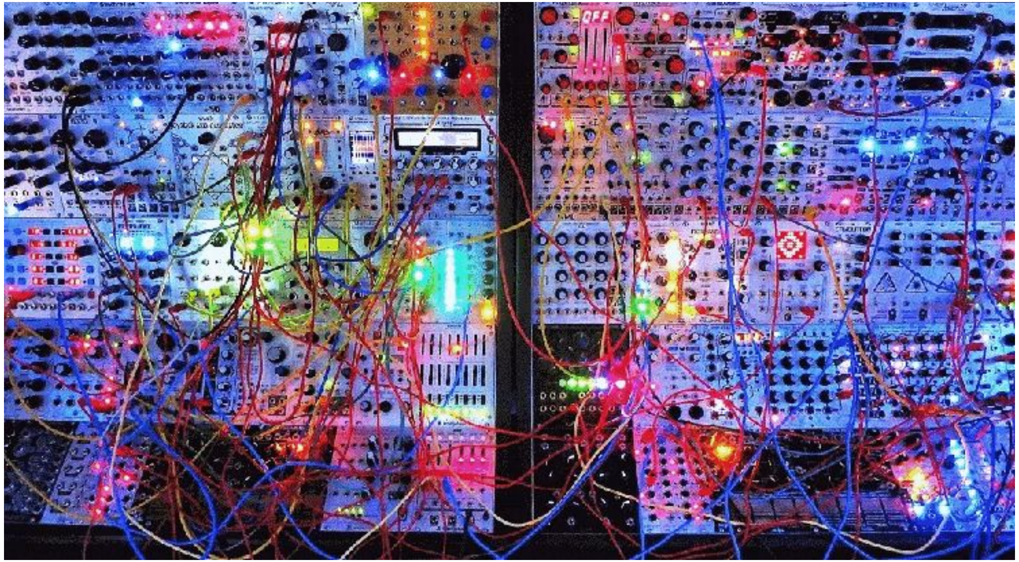
Overview

- Modular Synthesizer background and Terminology
- Problem Statement, Existing and Proposed Solutions
- Value Proposition and Comparison
- System Overview
- DMSP and Software Design
- Marketing and Engineering Requirements
- Alternate Design Matrices
- Challenges and Risks
- Critical Path, Gantt Chart, and Schedule.
- Tests and Results
- List of Components
- Supporting Courses
- Demonstration

What is Modular Synthesis?

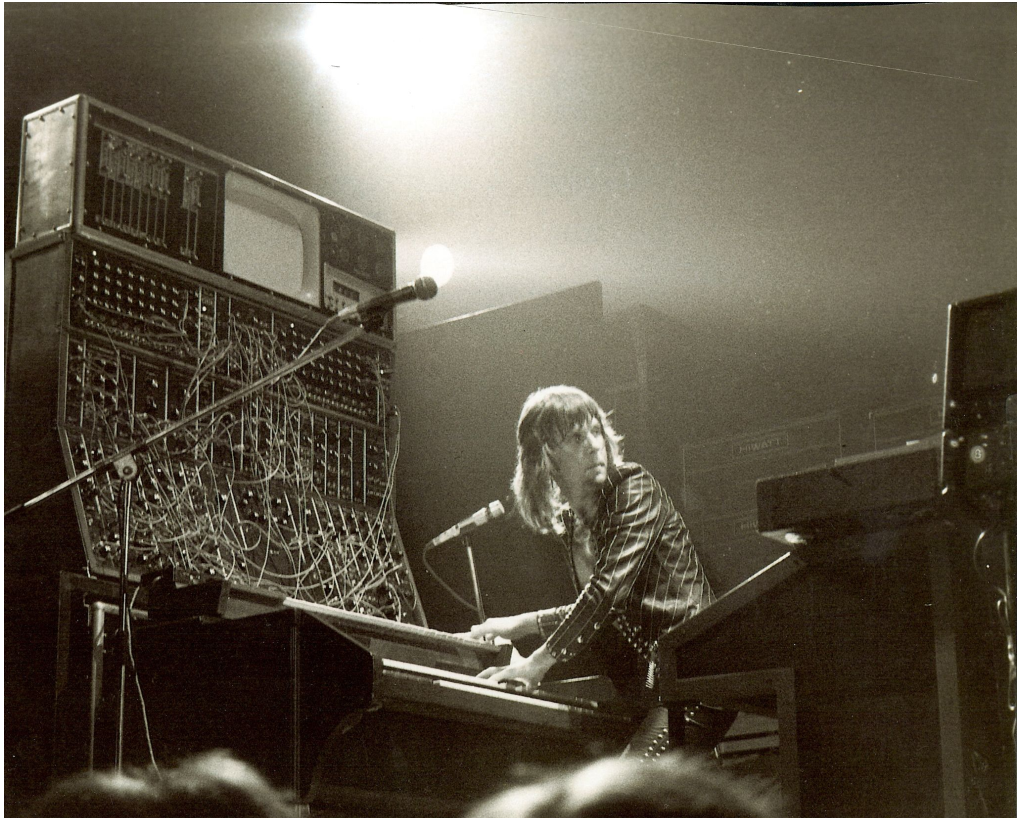
A Flexible Approach to Sound Design in a Module-Rack Format.

- No Fixed Architecture, Users design the signal path with patches.
- Easily scalable by adding new modules.
- Modules provide specific functions and can control aspects of others via control signals.



Types of Modules:
Signal Generator, Signal Modifier, Control.

Why Modular Synthesis?



Unmatched Flexibility

Ideal for experimental sound design and live performances.

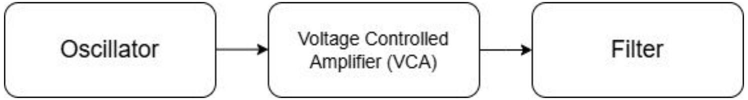
Hands-On Control

For Real-time manipulation and musical expression.

Scalability

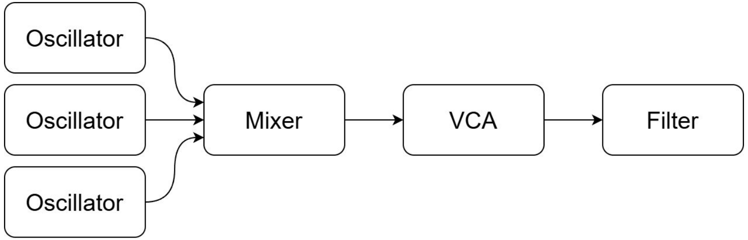
Start small and expand as needed.

Terminology



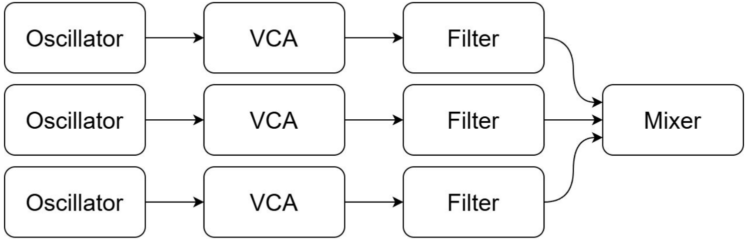
Monophonic

One frequency, One signal path



Paraphonic

Multiple frequencies, Shared signal path



Polyphonic

Multiple frequencies, Separate signal path

Problem Statement

Who: Musicians and sound designers who use hardware modular synthesizers

What: Traditional modular synthesizers do not support polyphony.

Why: Lack of polyphony restricts musical freedom. This contradicts the core philosophy of modular synthesis, which emphasizes complete control and flexibility in patching and sound design.

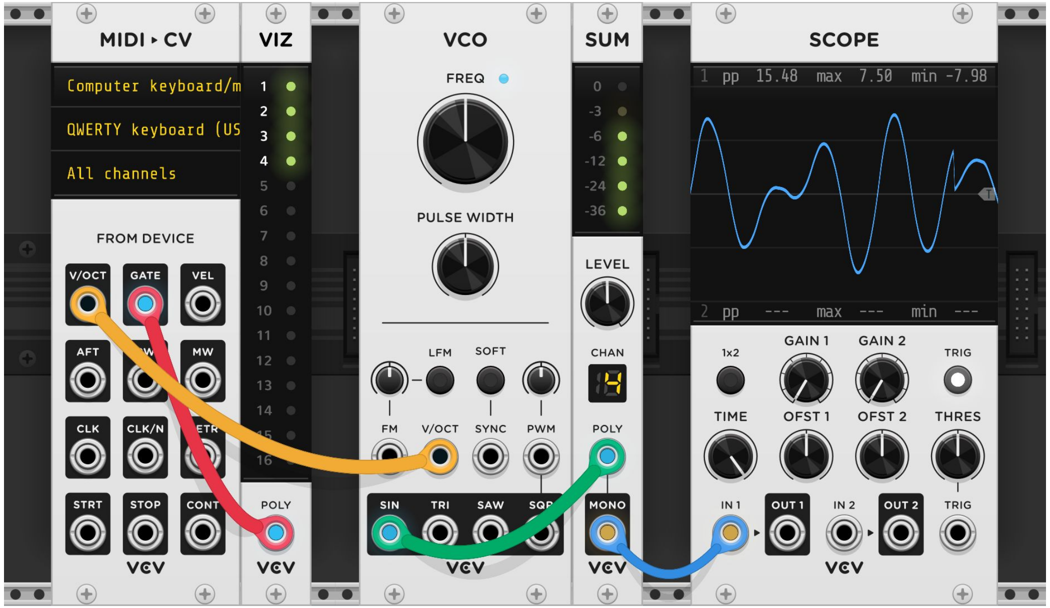
Virtual Racks

Advantages:

- Lower Cost than Hardware
- Supports Polyphony
- Accessible for Beginners

Disadvantages:

- Lack of Physical Control
- Latency Issues
- Increased Screen Time



Example: Virtual Rack Modules

Eurorack Multi Oscillators

Advantages:

- Analog Oscillators
- Physical Controls
- Industry Standard

Disadvantages:

- Paraphonic
- Complex: Non-Standardized CV Limits Control
- Expensive: Quad VCO = $419.99

Example: Eurorack Modules

CHORDS

Advantages:

- Supports Polyphony
- Physical Controls
- Lower cost per module

    can be reprogrammed for different purposes

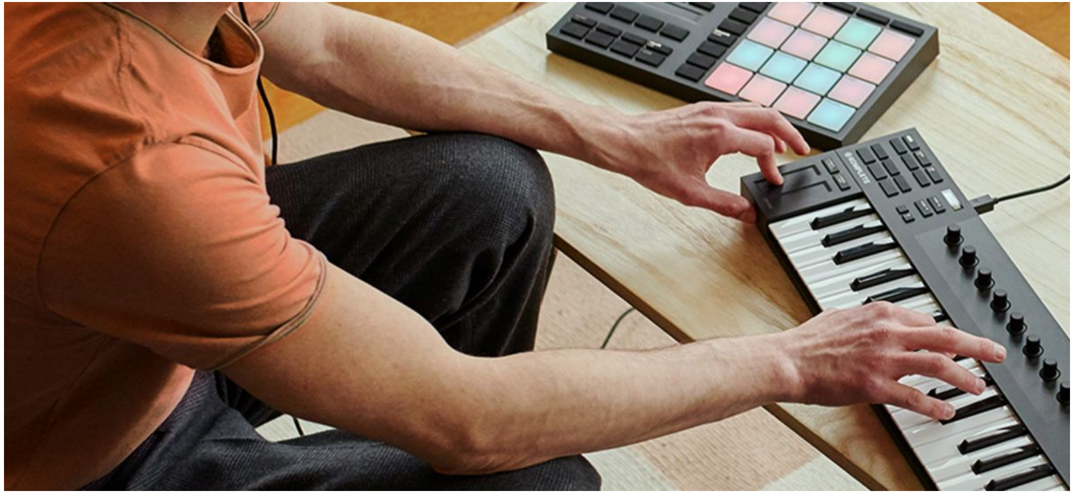
    no DAC or ADC circuitry for module to module communication

Disadvantages:

- Difficult to create Analog Modules
- Higher Latency than Eurorack

Value Proposition

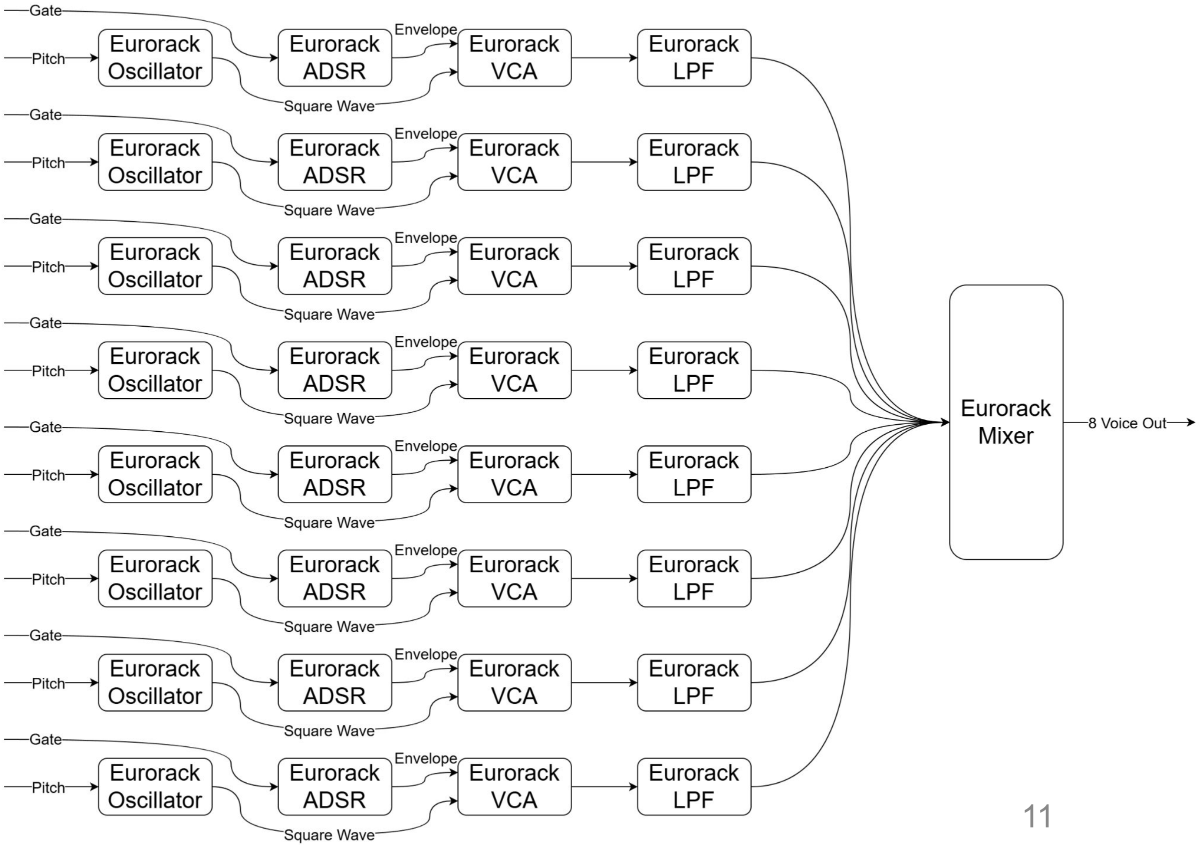
The CHORDS synthesizer helps musicians who want to make polyphonic sounds by providing a hardware modular synthesizer option with a low cost and physical controls.



Comparison

Eurorack 8 Voice Synth

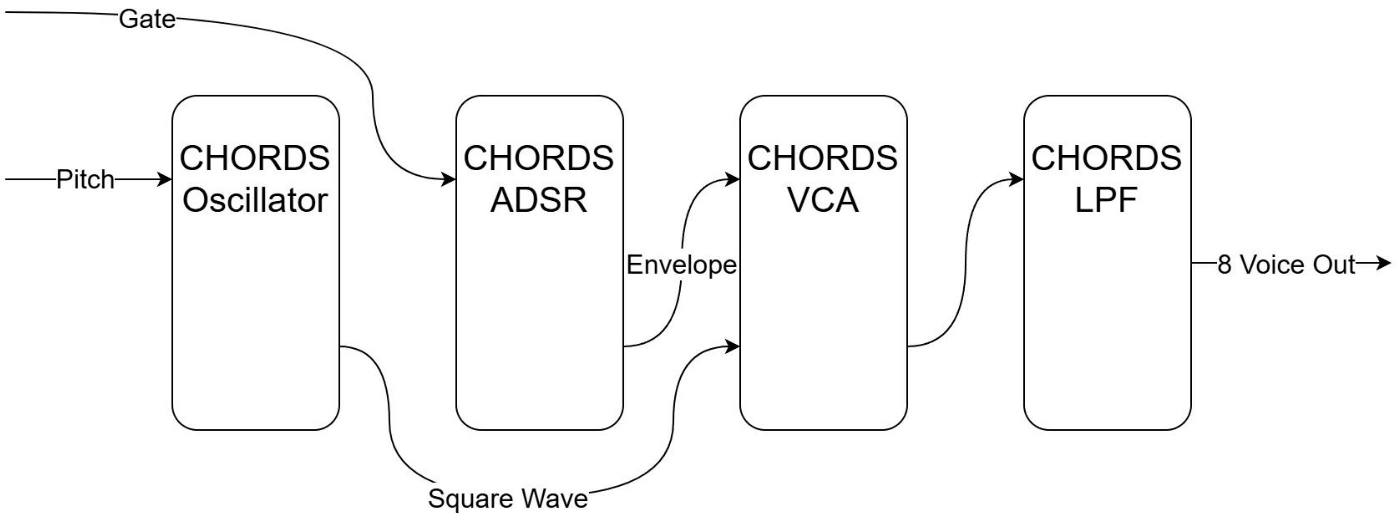
50+ Patch Cables



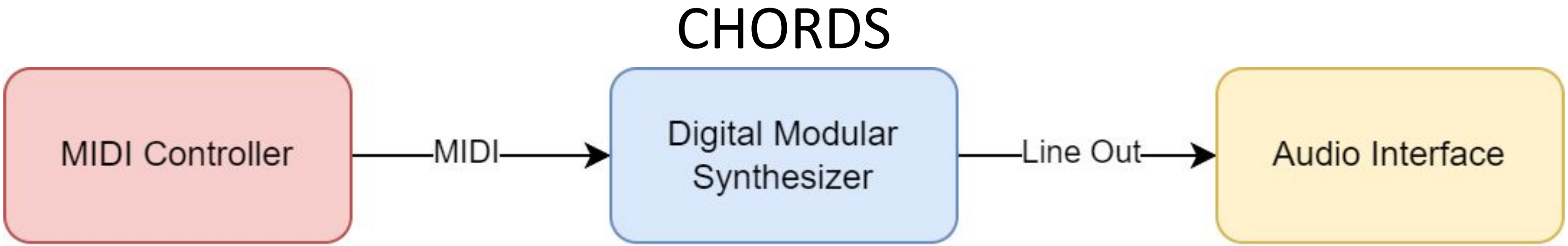
Comparison

CHORDS 8 Voice Synth

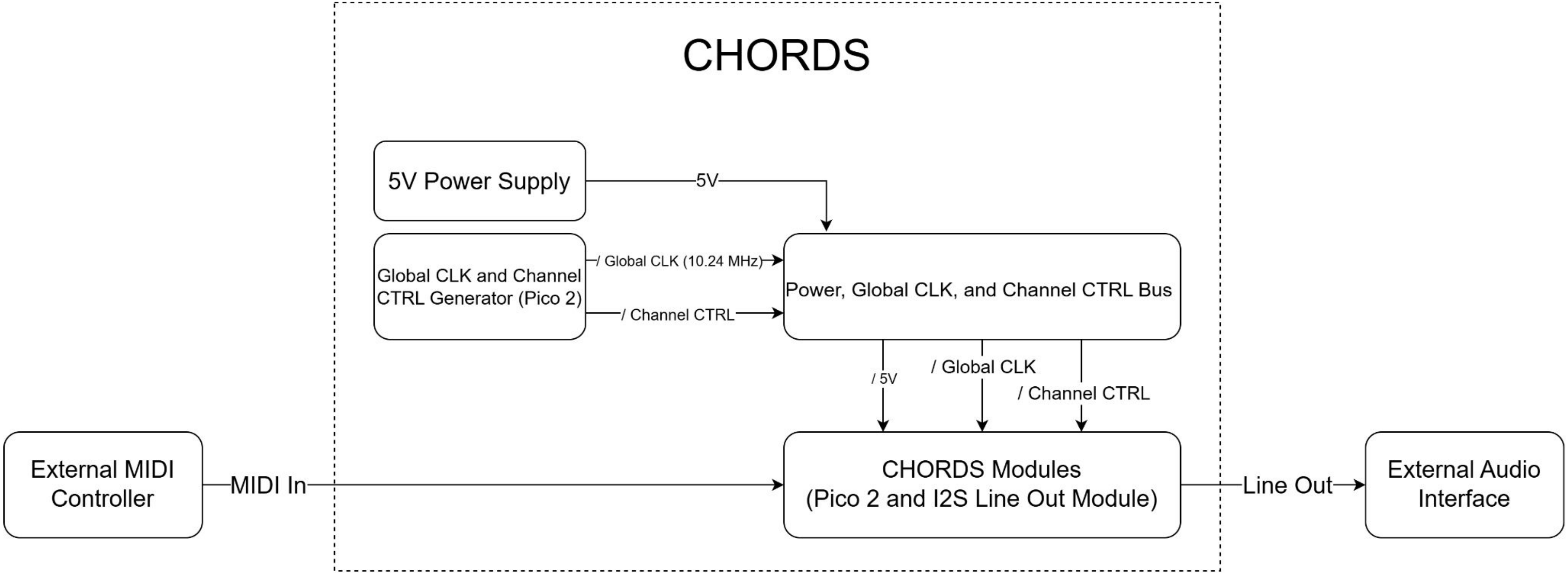
6 Patch Cables



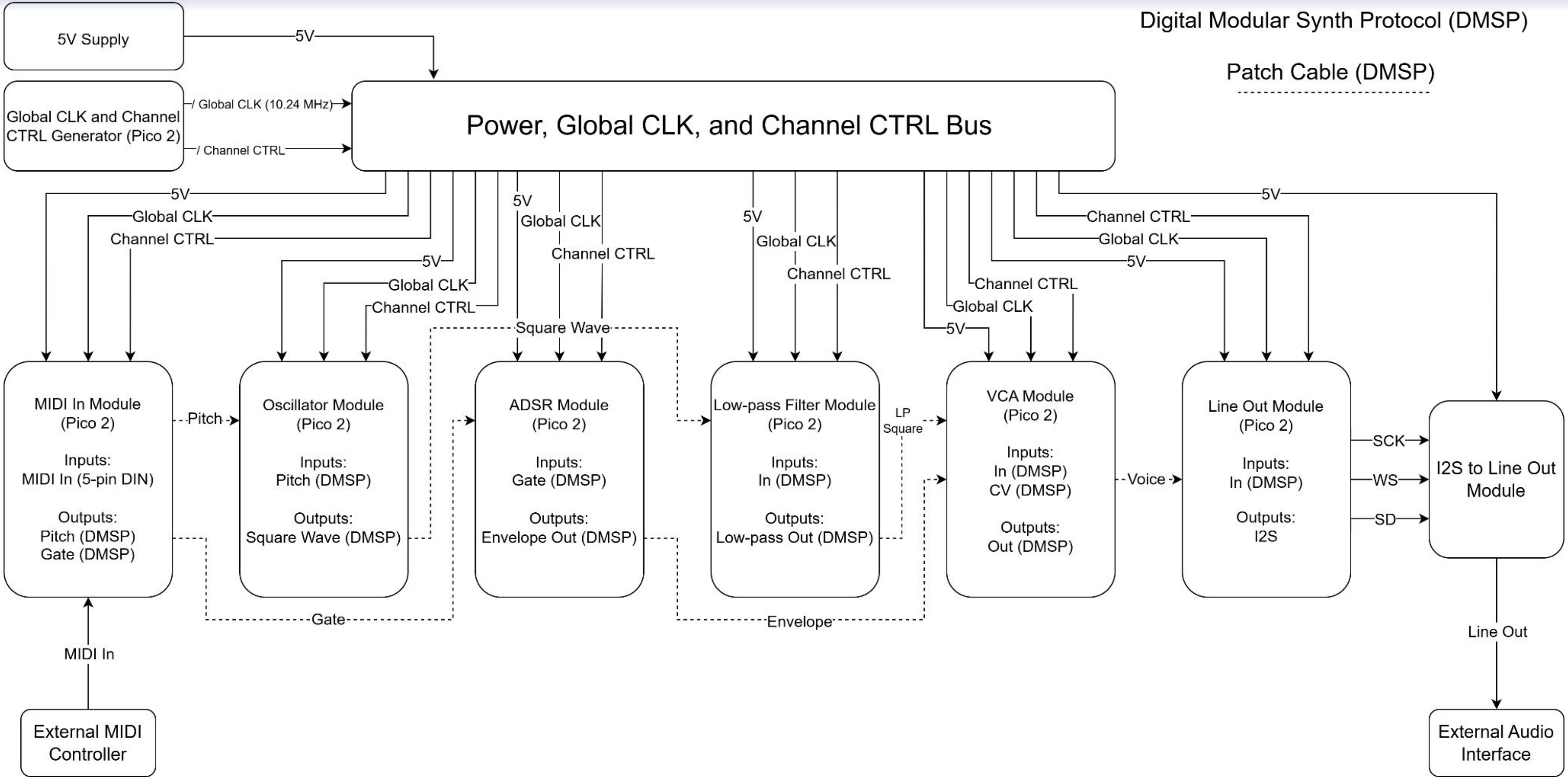
System Overview



System Overview

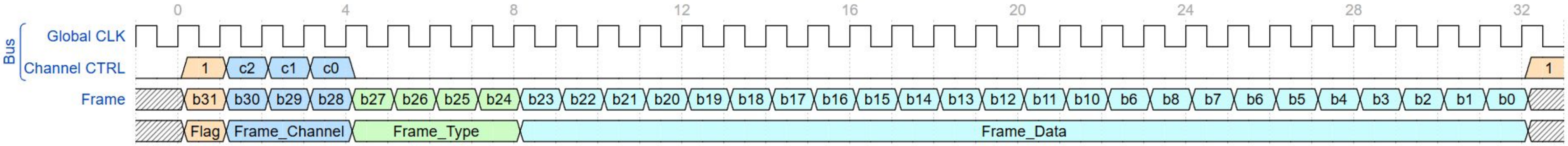


System Overview



DMSP

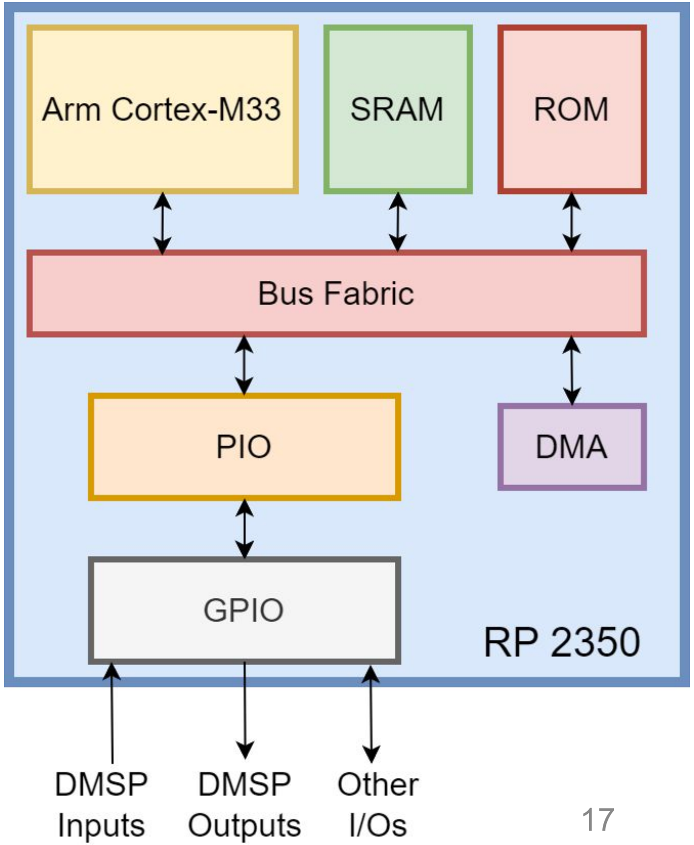
Digital Modular Synth Protocol



- Each frame is 32 bits:
- Channel Control Overhead 4 bits + Frame Type 4 bits + Frame Data 24 bits
- Start bit for synchronization, followed by 3 Channel Control bits allows for 8 Channels.
- 4 Frame Type bits allows for 16 frame types, eg. complete Midi messages, Control Signals, Audio.
- Each Frame contains 24 bits of Frame Data

Software Design

- DMSP utilizes PIO sm and DMA channels to minimize processor overhead
- RP 2350 Arm core runs module code, reads input buffer from SRAM and fills output buffer
- DMA transfers DMSP frames from SRAM to output PIO FIFO, vice versa
- PIO fills and empties its FIFOs in syncroniznation with Global CLK



Marketing Requirements

1. CHORDS provides a more versatile musical experience at an affordable price*
2. CHORDS is a hardware synthesizer, with a new digital communication interface
3. CHORDS will have polyphonic capabilities, with a minimum of 4 voice channels*
4. CHORDS and the DMSP will be compatible with MIDI commands for versatile user control
5. CHORDS is modular, and comes equipped with an oscillator, low-pass filter, ADSR, VCA, line out, and MIDI in modules
    a. CHORDS oscillator module is a table-lookup oscillator
    b. The CHORDS line out module will utilize a ¼” audio jack to send a 24-bit audio signal at 40 kHz to the user's audio interface or speaker system
    c. The CHORDS low-pass filter module will have a control knob for the musician to get their desired sound
    d. The CHORDS ADSR modules will allow the musician to set Attack, Decay, Sustain, and Release time with the control knobs
6. CHORDS will have an inexpensive custom case
7. CHORDS provides visual feedback using LEDs as power turns on or keys are pressed
8. CHORDS is a portable system that operates on battery power.
9. CHORDS will have low latency, ensuring that each musical note or control input is reflected quickly for a responsive playing experience.

Engineering Requirements

1. Utilizing the RP 2350 Microcontroller, CHORDS is estimated to cost $200 or less (MR 1)*
2. CHORDS modules will have physical interfaces, such as knobs, switches, and buttons, to control parameters (MR 2)
3. CHORDS will be Polyphonic, allowing for a minimum of 4 voice channels to be played at one time. DMSP has 3 channel bits, which supports a maximum of 8 voice channels (MR 3)*
4. The MIDI, ADSR, and VCA modules shall operate with a maximum latency of 5ms and the filter, oscillator, and I2S with a maximum latency of 10ms (MR 9)*
5. CHORDS will be controllable with a standard MIDI controller. Using the IC (6N138) MIDI information will be converted into DMSP signals containing frequency and gate data (MR 4)
6. CHORDS oscillator module will be tuned to 440 Hz for the A1 note on MIDI keyboard (MR 5a)
7. CHORDS Inter-Integrated Circuit Sound (I2S) module will run at a sample rate of 24-bit at 40 kHz and Total Harmonic Distortion (THD) will be under 1%, ensuring high audio fidelity with minimal distortion.(MR 5b)
8. CHORDS Low-pass filter will operate from 0Hz-20kHz (MR 5c)
9. CHORDS case will be 3d printed in PLA (MR 6)
10. CHORDS will be run on a 5 V battery for portability and ripple under 10 mV peak-to-peak(MR 8)

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Alternative Design Matrix for Output Module

	I2S Stereo Decoder (AdaFruit)	I2S Audio Breakout (Sparkfun)	ESP32 with I2S	DAC (HiFiBerry)
Cost (0.45)	0.45 ($6.95)	0.22 ($17.95)	0.28 ($22.99)	0.05 ($58.58)
Output Quality (Sample Rate: 24-bit 44.1KHz) (0.33)	0.175 (24-bit 44.1KHz)	0.175 (24-bit 44.1KHz)	0.20 (24-bit 44.1KHz, less noise)	0.45 (24-bit 192KHz)
Capability & Additional Features (0.22)	0.225	0.10	0.275	0.40
Score	30.975%	17.875%	25.25%	25.9%

Alternative Design Matrix for Microcontroller

	RP2350 (pico 2)	RP2040 (pico 1)	Teensy 4.0	ESP8266
Cost (0.5)	0.3243 (5.00$)	0.4054 (4.00$)	0.0676 (23.80$)	0.2027 (7.99$)
Clock Speed (0.25)	0.2442 (150 MHz)	0.1250 (100 MHz)	0.4769 (600 MHz)	0.1538 (80 MHz)
Memory (0.25)	0.2942 (520 KB)	0.1541 (264 KB)	0.4703 (1024 KB)	0.0813 (112 KB)
Score	29.68%	27.25%	27.06%	16.01%

Challenges and Risks

Risks

1. **Latency between input and output:** Rating = 15; Consequence = 3, Likelihood = 5
   a. Factors: Too many modules and Inefficient implementation of DMSP or DSP algorithms
   b. Contingency Plan: Optimize each module to reduce latency added to patch, Ensure Modules meet ER 4.

1. **Signal Integrity of DMSP and Global CLK Bus:** Rating = 15; Consequence = 5, Likelihood = 3
   b. Factors: cable type and length, distances between modules or latency causing synchronization issues
   c. Contingency Plan: consistent hardware implementation for bus and DMSP connections

1. **Running out of RAM or ARM Core overload:** Rating = 10; Consequence = 5, Likelihood = 2
   b. Factors: Buffer size, DSP Algorithm implementation,
   c. Contingency Plan: Reduce buffer size and optimize code, or reduce module feature

Challenges and Risks

Challenges

1. **Noise:** CHORDS is intended to provide clean digital waveforms for the Musician
   a. Factors: Signal being sent to separated modules, cheap components
   b. Plan: Testing Signal-to-Noise Ratio, applying filters to remove unwanted noise

1. **Clock Distribution:** All of the modules need to be synchronized
   b. Factors: Improper clock frequency, inconsistent distribution of DMSP
   c. Plan: Test Global Clock output individually and collectively

1. **Module Latency:** Latency is a major concern for all digital audio systems
   b. Factors: Each CHORDS module will introduce latency into the patch
   c. Plan: Testing latency and improving connections between modules can minimize latency

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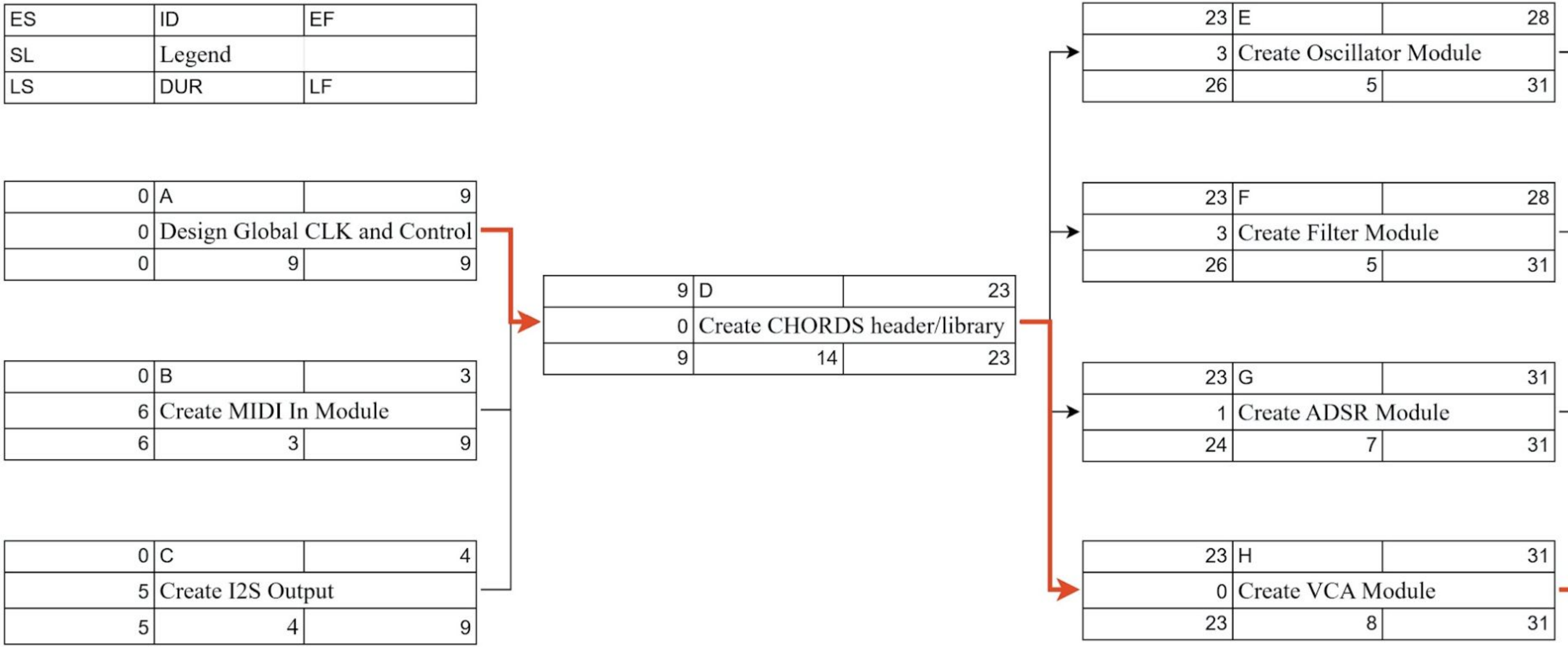
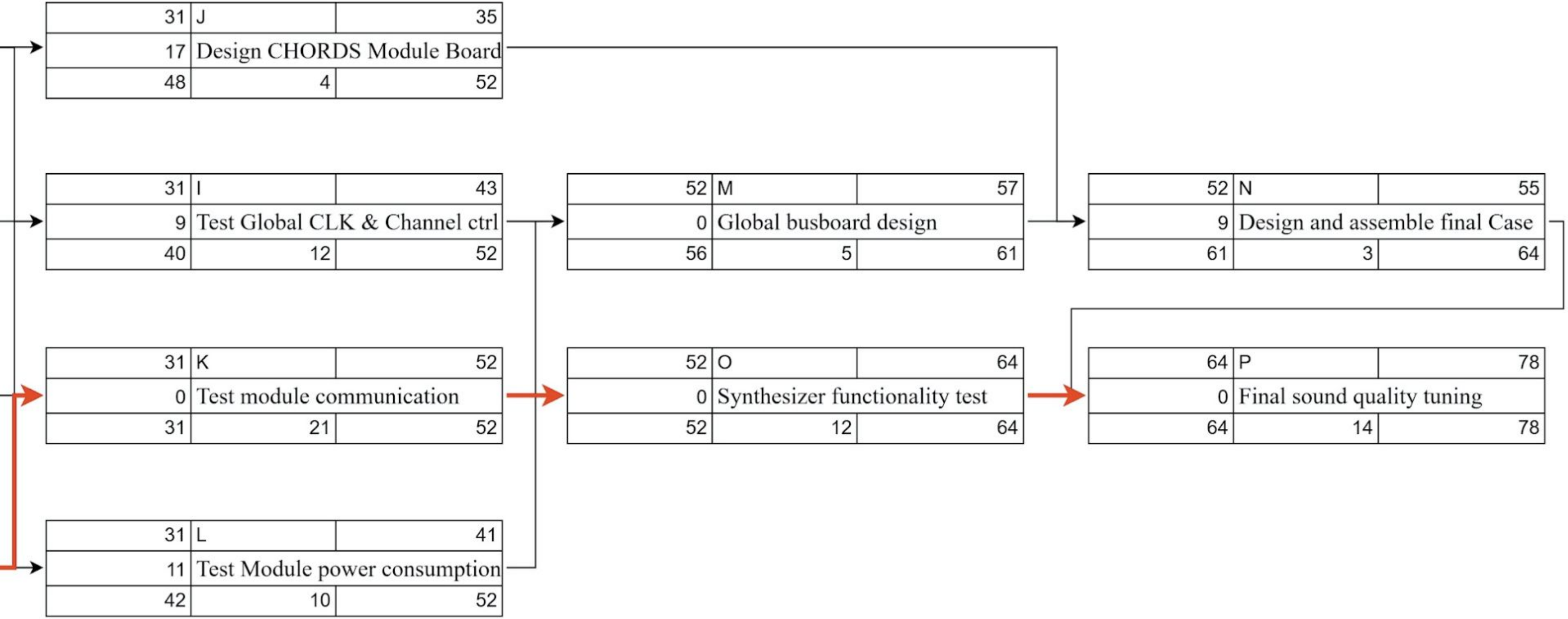
Critical Path (Winter)



Critical Path (Spring)



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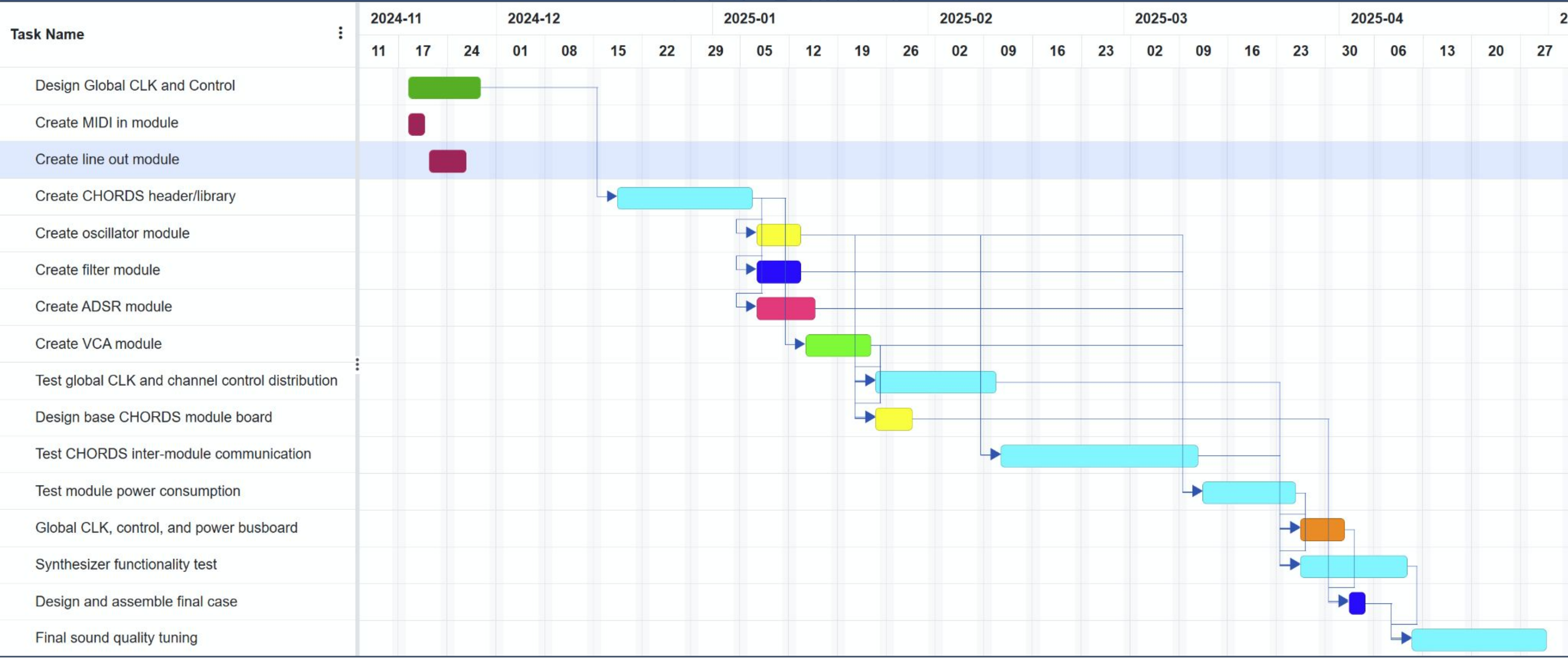
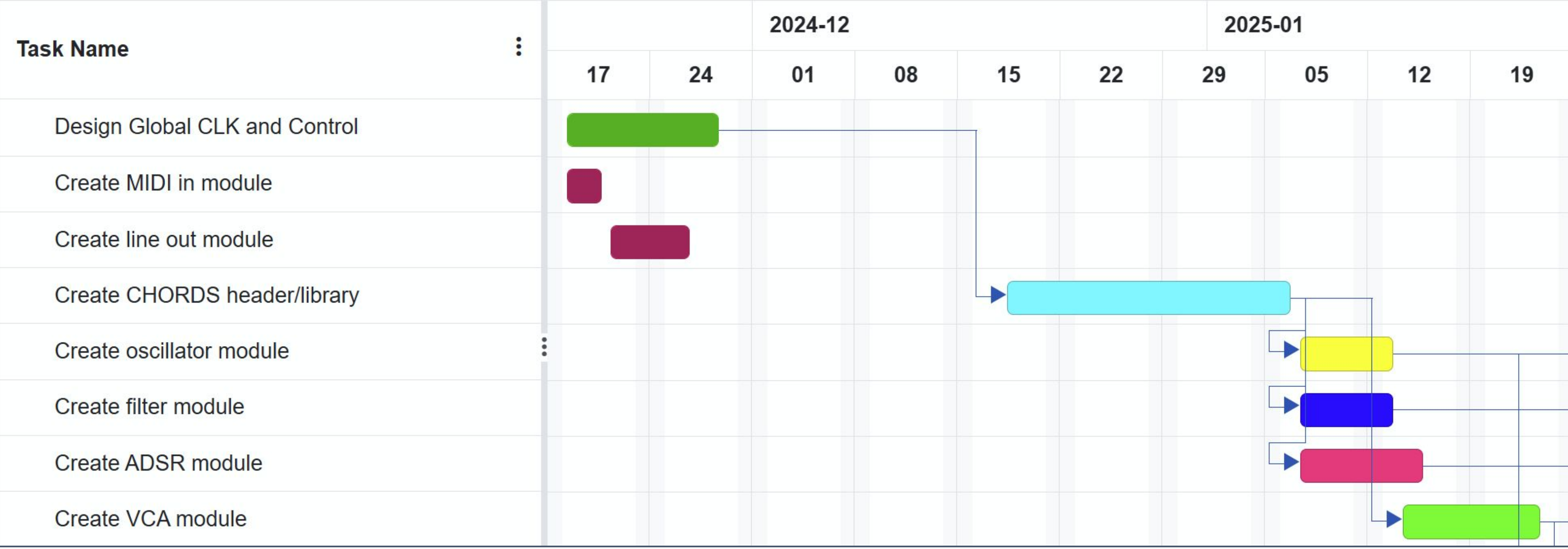
Gantt Chart



Julius: Bjorn: Madison: Everyone:

Gantt Chart



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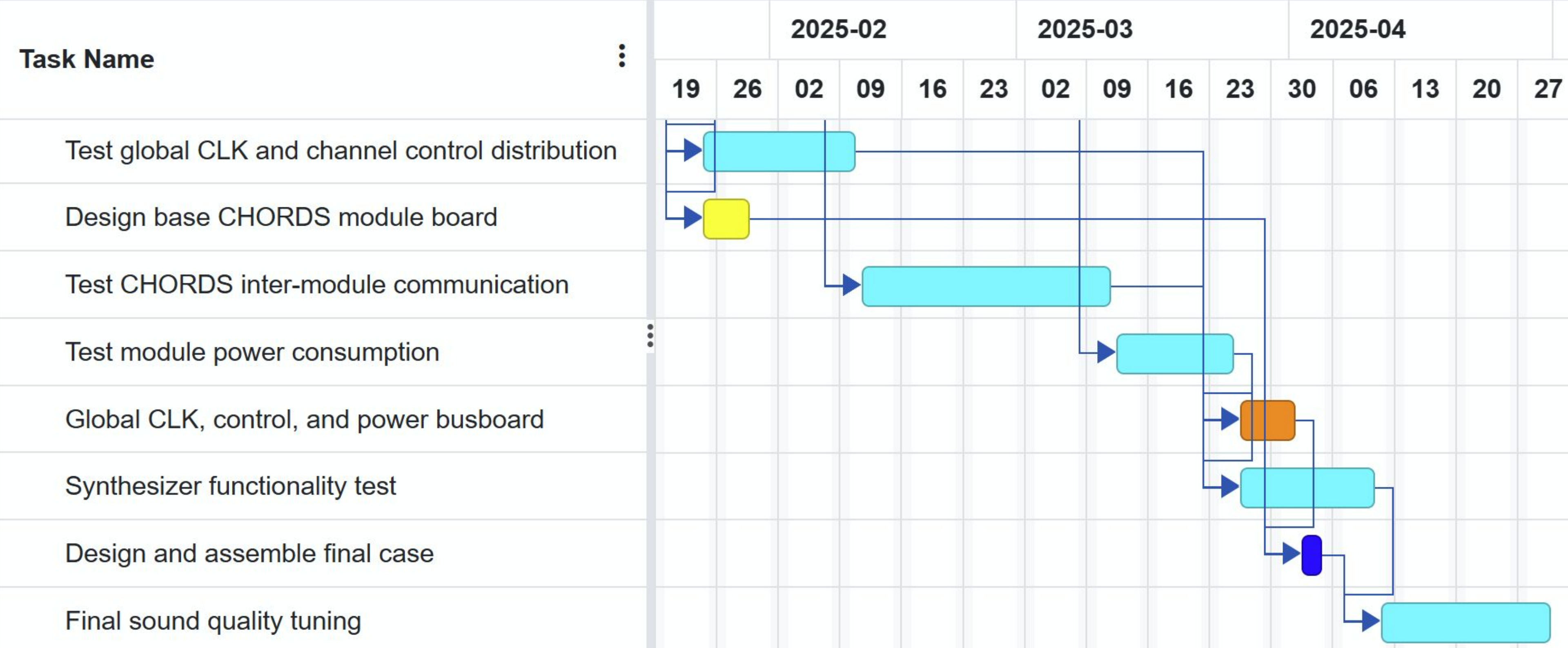
Gantt Chart



Julius: Bjorn: Madison: Everyone:

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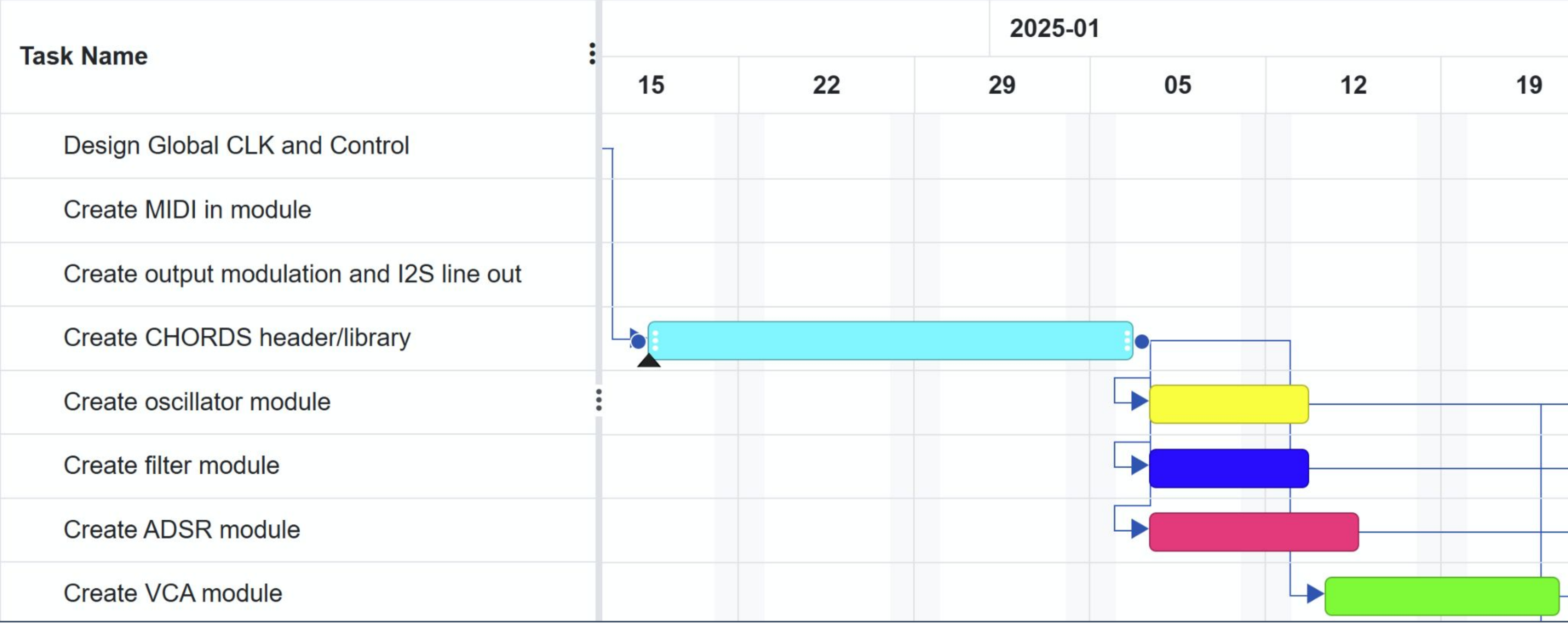
Winter Gantt Chart



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Winter Schedule

2	Create CHORDS header/library	Everyone	14 days	2024-12-18	2025-01-06
4	Create oscillator module	Madison	5 days	2025-01-07	2025-01-13
5	Create filter module	Julius	5 days	2025-01-07	2025-01-13
6	Create ADSR module	Bjorn	7 days	2025-01-07	2025-01-15
7	Create VCA module	Julius, Madison	8 days	2025-01-14	2025-01-23

Julius: (blue) Bjorn: (pink) Madison: (yellow) Everyone: (cyan)

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Schedule

Julius: Bjorn: Madison:

ID	Task Name	Start	End	Duration	Progress %
1	Design Global CLK and Control	2024-11-18	2024-11-28	9 days	100
3	Create MIDI in module	2024-11-18	2024-11-20	3 days	100
8	Create line out module	2024-11-21	2024-11-26	4 days	100
2	Create CHORDS header/library	2024-12-18	2025-01-06	14 days	0
4	Create oscillator module	2025-01-07	2025-01-13	5 days	0
5	Create filter module	2025-01-07	2025-01-13	5 days	0
6	Create ADSR module	2025-01-07	2025-01-15	7 days	0
7	Create VCA module	2025-01-14	2025-01-23	8 days	0
9	Test global CLK and channel control distribution	2025-01-24	2025-02-10	12 days	0
12	Design base CHORDS module board	2025-01-24	2025-01-29	4 days	0
10	Test CHORDS inter-module communication	2025-02-11	2025-03-11	21 days	0
11	Test module power consumption	2025-03-12	2025-03-25	10 days	0
13	Global CLK, control, and power busboard	2025-03-26	2025-04-01	5 days	0
15	Synthesizer functionality test	2025-03-26	2025-04-10	12 days	0
14	Design and assemble final case	2025-04-02	2025-04-04	3 days	0
16	Final sound quality tuning	2025-04-11	2025-04-30	14 days	0

Planned Tests

Test Number	Test Objective	Related ER	Status	Notes
Test 1	MIDI Input and Latency Test	ER. 4	Complete	delay < 5ms
Test 2	Global CLK and Channel control synchronization	ER. 5	Incomplete	CLK = 10.24 +/- 0.01 MHz
Test 3	Total Harmonic Distortion (THD) of Oscillator via I2S Output Module	ER. 6	Incomplete	THD < 1%

Test 1

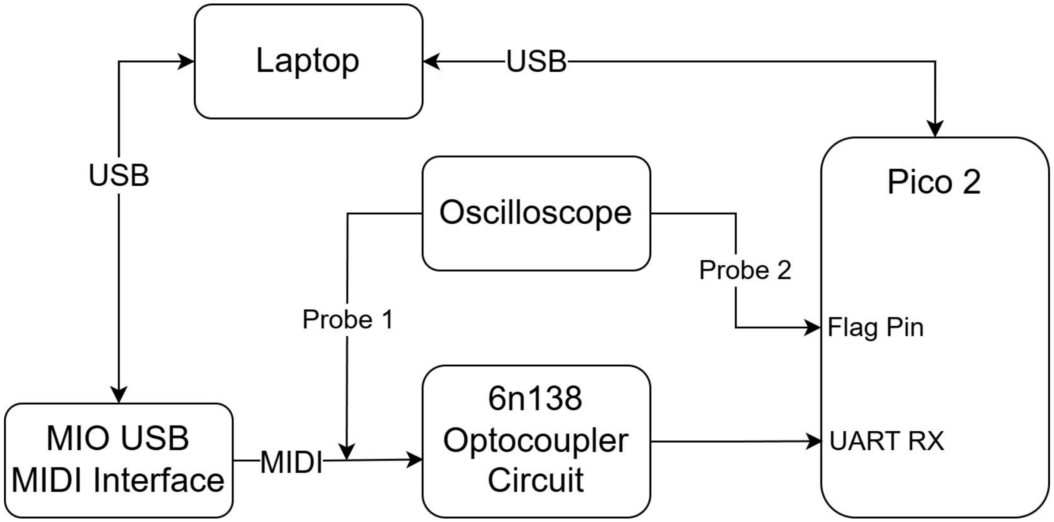
MIDI Input and Latency Test

Purpose:

- Test that the Pico 2 can receive MIDI messages and correctly interpret them within our latency requirement of 5ms (ER 4, 5)

Setup:

- Hardware UART used to receive MIDI messages
- Protection Circuit built to protect RX Pin
- MIO MIDI USB Interface to send MIDI messages
- Flag pin is set when UART has data available, cleared when MIDI is decoded
- Oscilloscope measures timing of MIDI and Flag pin signals to determine latency
- RP 2350 prints MIDI messages to USB serial monitor



Test 1

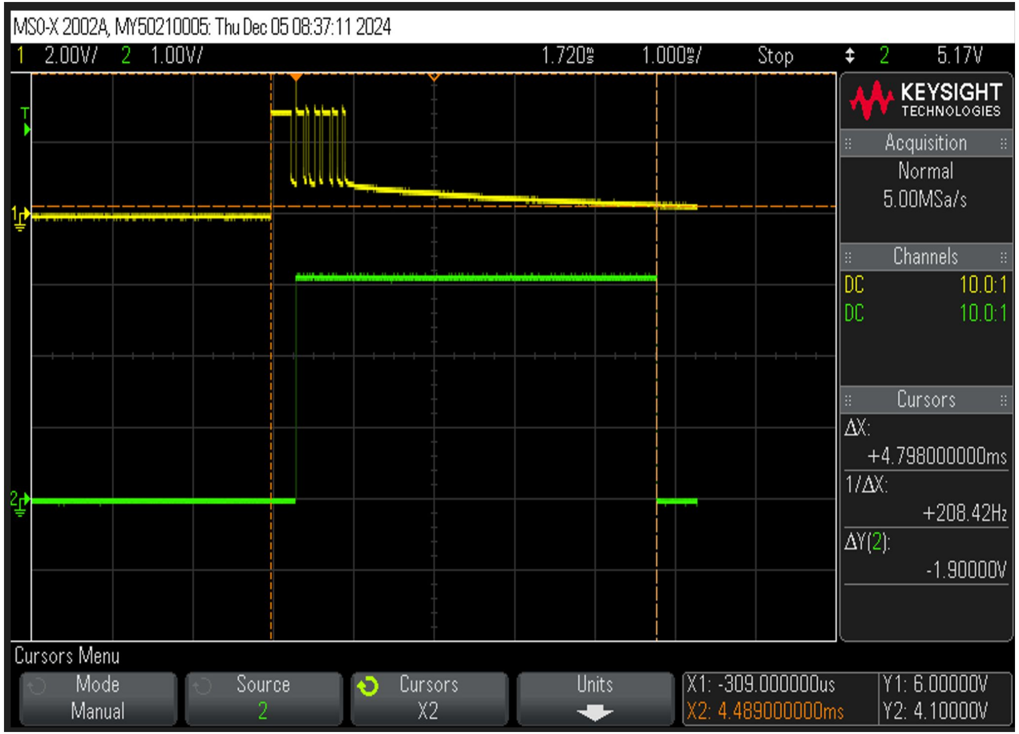
MIDI Input and Latency Test

Results:

- MIDI messages correctly interpreted
- Latency is under 5 ms goal at 4.798 ms

Conclusion:

This test was successful and satisfies our test objective. When completed, other modules will undergo latency tests with a similar setup.



List of Components

Part/ Quantity	Price	Description	Link	Test	ER#
PICO-2 (RP 2350)	$5 (x8)	Board used for Global Clock, DMSP, and Modules	https://www.adafruit.com/product/6006	ST.1 FT.1 FT.2	ER.1 ER.2 ER.3 ER.5
I2S output Board	~$10	Audio output module	https://www.adafruit.com/product/3678	ST.1	ER.1 ER.2 ER.3
MIDI Controller	~$100 (Provided)	MIDI keyboard that will trigger input data	https://www.amazon.com/Nektar-SE49-49-Key-Controller-Keyboard/dp/B01MF9EJPG?th=1	ST.1	ER.4
3D printing	$20	For Case, knobs, and sliders	https://library.sonoma.edu/create/makerspace	N/A	MR.6
IC (6N138)	$0.96	MIDI Input module	https://www.digikey.com/en/products/detail/lite-on-inc./6N138/1969179	ST.1 FT.1	ER.4
Total Cost					$170.96

Supporting Courses

- EE 210 Digital Circuits and Design
- EE 310/310L Microprocessors and System Design
- EE 334/334L Microelectronic Circuits
- EE 400 Linear Systems Theory
- EE 410 Advanced Digital System Design
- EE 442/442L Analog And Digital Communications

MIDI In Demo

Questions

Thank You

Questions/Comments