Requirements Specification
Embedded DSP Eurorack Synthesizer Module

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1. Introduction

This document specifies the requirements for the development of a Eurorack-compatible embedded DSP synthesizer module. The module shall process audio signals in real time and provide DSP-based sound manipulation. An STM32H7 microcontroller is the target platform for this project.

2. Initial Situation

- A Hardware Revision 2 PCB design exists but has not yet been fully validated or manufactured.
- No firmware stack is available at the start of the project.
- The audio codec, control inputs, and user interface elements require integration and functional verification.
- The exact DSP functionality has not yet been fully specified and will intentionally remain partially unspecified during the project implementation.

3. Objectives and Expected Benefits

- Creation of a stable and extensible DSP-based Eurorack module.
- Real-time audio processing with low latency suitable for musical applications.
- Development of a reusable firmware and DSP architecture to support future extensions and additional modules.
- Reliable operation within Eurorack power and signal constraints.

4. Product Usage / Intended Use

- Intended for use as a Eurorack synthesizer module in electronic music production and sound experimentation.
- Processing of incoming audio signals and/or internal audio signal generation.
- Control via control voltage inputs, V/Oct input, gate signals, faders, and buttons.
- RGB LEDs shall provide visual user feedback.
- Target users include musicians, sound designers, and experimental audio users.

5. Functional Requirements

Hardware

- The system shall boot on Hardware Revision 2 and support flashing and debugging via SWD.
- Audio acquisition and playback shall be performed using the external audio codec mounted on the PCB.
- The system shall safely handle maximum and worst-case Eurorack signal levels without damaging the audio codec or MCU ADCs.
- Control inputs such as CV, V/Oct, and gate signals shall be supported.
- Potentiometers shall be read via ADC channels with adequate noise performance and resolution.
- Button inputs shall be handled with proper debouncing.
- Overall noise performance shall be suitable for music production.
- The analog audio input and output stages shall provide sufficient bandwidth across the audible frequency range while suppressing DC offsets and high-frequency interference.

Firmware

- Audio playback shall be implemented using a double-buffered DMA-based audio I/O mechanism.
- The system shall perform real-time DSP processing on continuous audio streams.
- The maximum available memory shall be utilized for audio buffering to enable tape-like or sampler-style operation.
- RGB LEDs (WS2812) shall be controllable by the firmware.
- The firmware shall support multitasking using a real-time operating system.
- While low-power optimization is not a primary objective, reasonable energy consumption shall be considered.

6. Non-Functional Requirements

- Deterministic real-time audio processing behavior.
- End-to-end audio latency suitable for live performance and not exceeding 20 ms.
- Stable operation during continuous use.
- No audio dropouts, clicks, pops, or other audible artifacts caused by crashes, reboots, insufficient performance, or poorly optimized drivers or DSP algorithms.
- Modular, maintainable, and extensible firmware architecture.
- Audio signal quality sufficient for further DSP development and experimentation.

7. Scope of Delivery

- Assembled and verified Hardware Revision 2.
- KiCad project or PDFs including:
  - Schematics of PCB design
  - Layout and routing of PCB design
  - Complete BOM
  - Spice simulations of analog Input/Output stages
- Firmware project including:
  - Complete and buildable Codebase featuring the entirety of the projects scope
  - STM32CubeMX configuration
  - CMake-based build system
  - FreeRTOS integration
- Basic DSP functionality such as filtering.
- Implemented and tested control and user interface functionality.
- Basic documentation for setup, build, and usage.

8. Project Phases and Milestones

- **M1:** Hardware assembly and power verification.
- **M2:** Functional hardware and peripheral testing.
- **M3:** Audio engine implementation.
- **M4:** DSP algorithm development.
- **M5:** Control interface implementation.
- **M6:** User interface integration and testing.

Further details are provided in the project plan.

9. Open Issues / Open Questions

- Final DSP feature set to be defined.
- Achievable calibration accuracy for V/Oct tracking.
- Long-term extensibility of the DSP framework.
- Noise performance and overall audio quality of the analog input and output stages, currently evaluated only through SPICE simulations.

10. Acceptance Criteria

- Hardware Revision 2 operates reliably within a Eurorack system.
- No front panel is required; the module only needs to be patchable via 3.5 mm mono jack cables.
- Audio input can be routed directly to the output without audible artifacts (through mode).
- Real-time DSP processing without buffer underruns.
- All control inputs and user interface elements function as specified.
- The system is flashable, debuggable, and reproducible using the documented build process.
- The Codebase is well-structured and offers a fundament/framework for development of further MCU-based Eurorack modules.
- CAD project is well structured and offers insight and comments on design decisions.