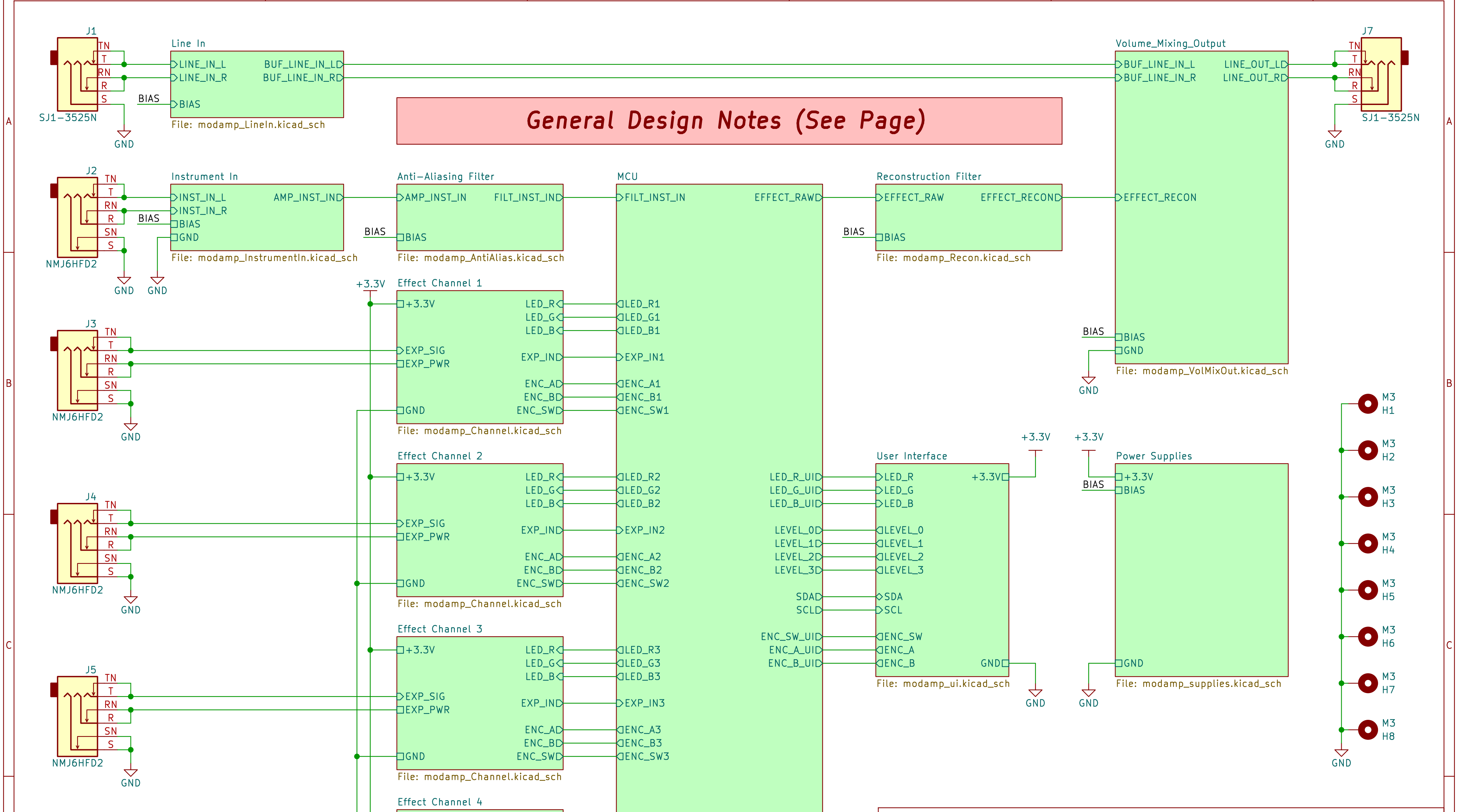


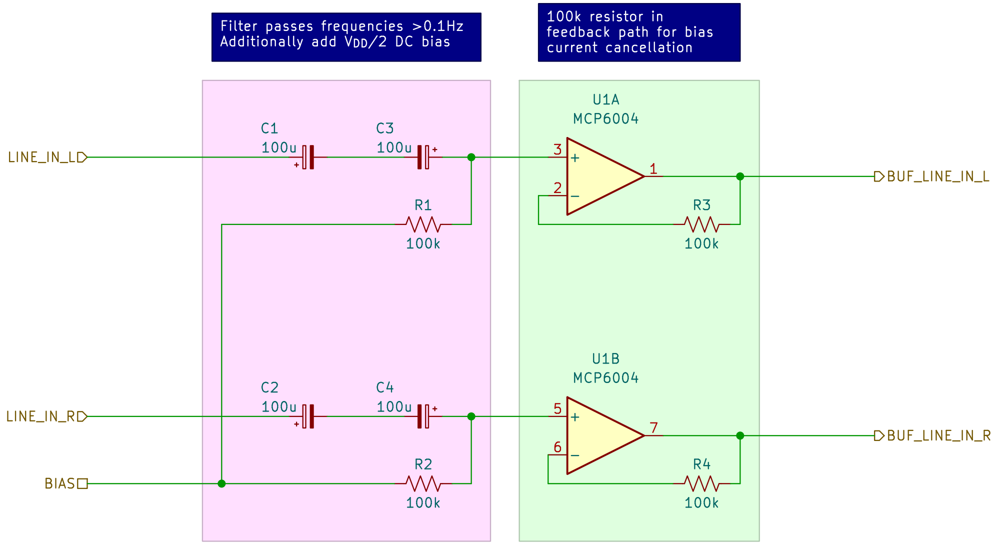
Ishaan Govindarajan

Sheet: /

File: Amplifier Hardware R1.kicad_sch

Title: Digital Audio Effects Processor

Size: A4	Date: 2023-11-26	Rev: A
KiCad E.D.A. kicad 7.0.5		Id: 1/14

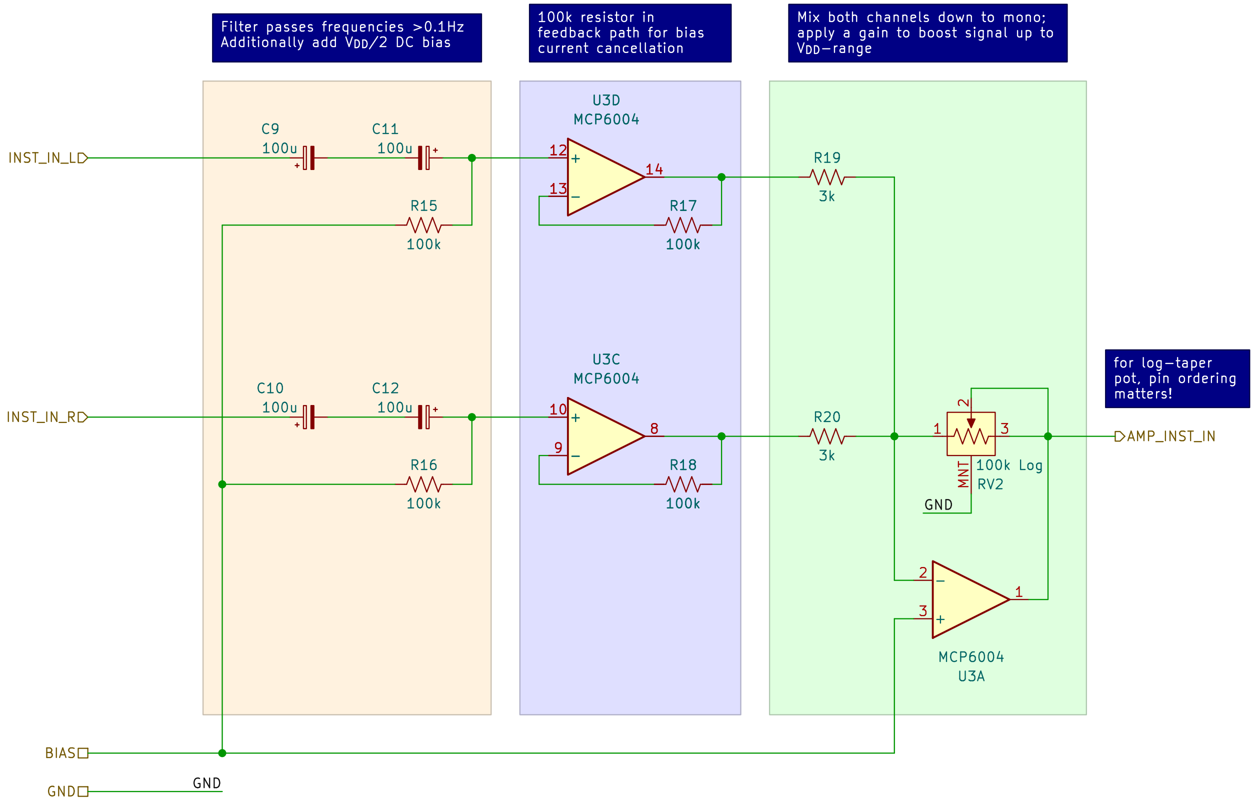


Ishaan Govindarajan

Sheet: /Line In/
File: modamp_LineIn.kicad_sch

Title: Digital Audio Effects Processor

Size: A4	Date: 2023-11-26	**Rev: A**
KiCad E.D.A. kicad 7.0.5		Id: 2/14

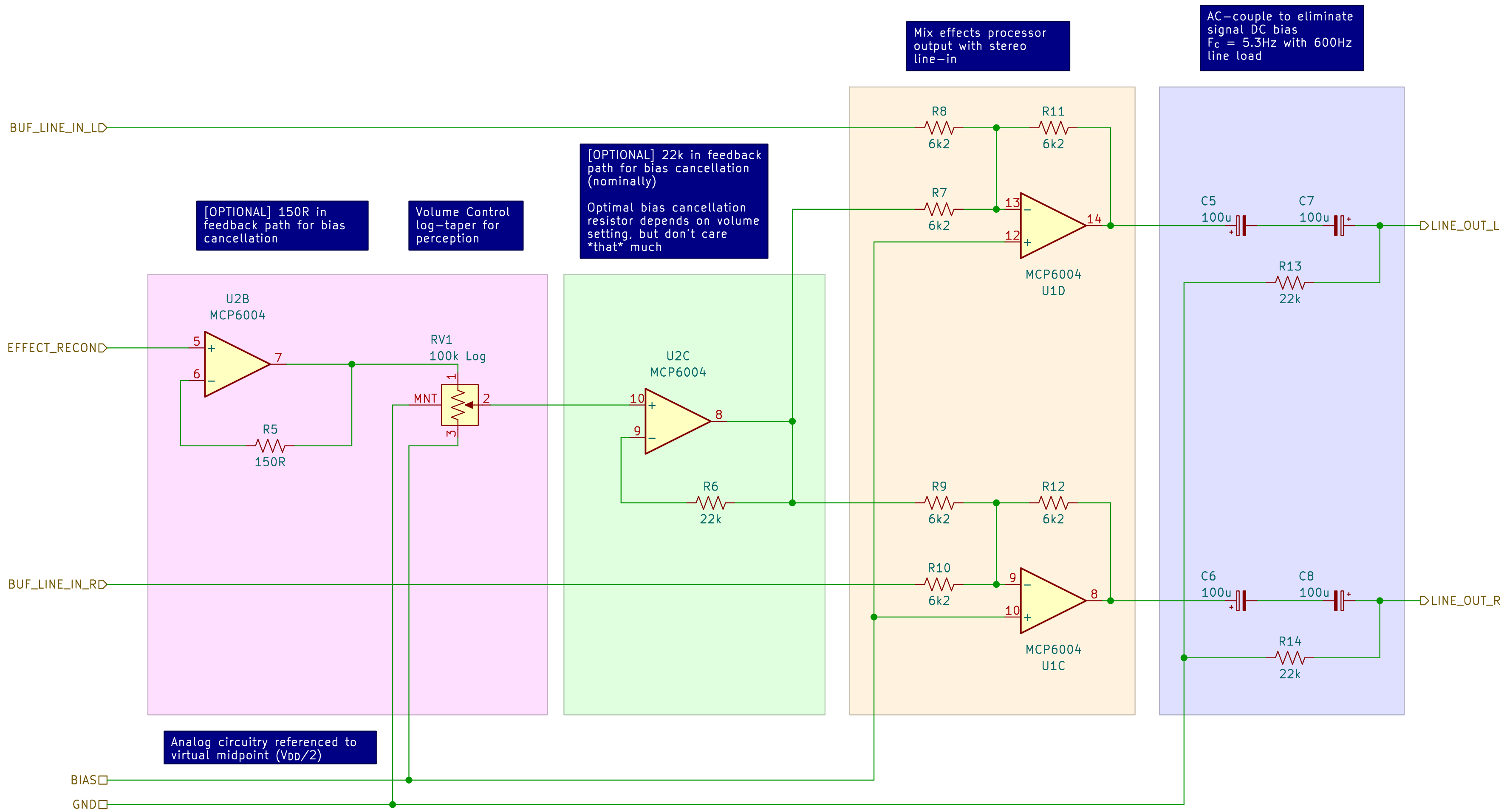


Ishaan Govindarajan

Sheet: /Instrument In/
File: modamp_InstrumentIn.kicad_sch

Title: Digital Audio Effects Processor

Size: A4	Date: 2023-11-26	Rev: A
KiCad E.D.A. kicad 7.0.5		Id: 3/14



Ishaan Govindarajan

Sheet: /Volume_Mixing_Output/

File: modamp_VolMixOut.kicad_sch

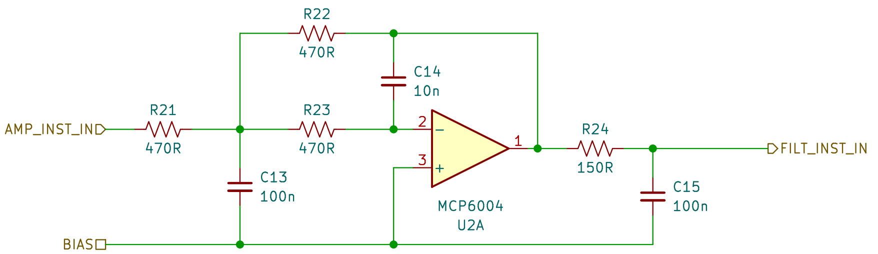
Title: Digital Audio Effects Processor

Size: A4	Date: 2023-11-26	**Rev: A**
KiCad E.D.A. kicad 7.0.5		Id: 4/14

3rd–order multiple–feedback butterworth filter with Av = 1 and F_c = 10.7kHz

Passband isn't *perfect* –– Q is a little higher than it should be, but pretty good with regular component values

Filter designed around easy capacitor values; lends itself to medium–low resistance values which is good for drive strength and noise



Using film capacitors for decent tolerance, elimination of microphonics, and mitigation of non–linearity from DC bias

Ishaan Govindarajan

Sheet: /Anti–Aliasing Filter/
File: modamp_AntiAlias.kicad_sch

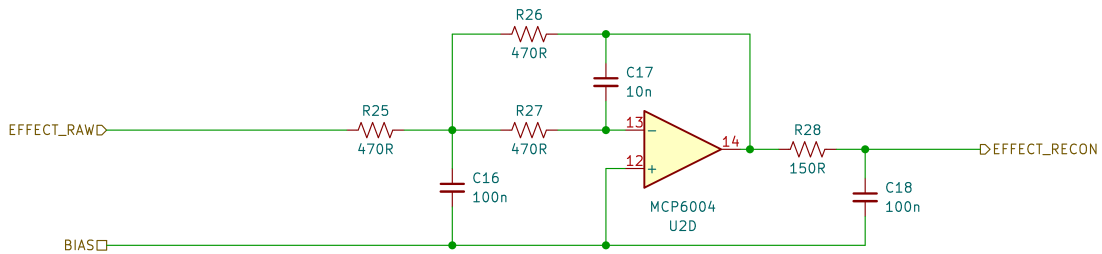
Title: Digital Audio Effects Processor

Size: A4	Date: 2023–11–26	**Rev: A**
KiCad E.D.A. kicad 7.0.5		Id: 5/14

3rd–order multiple–feedback butterworth filter with Av = 1 and F_c = 10.7kHz

Passband isn't *perfect* –– Q is a little higher than it should be, but pretty good with regular component values

Filter designed around easy capacitor values; lends itself to medium–low resistance values which is good for drive strength and noise



Using film capacitors for decent tolerance, elimination of microphonics, and mitigation of non–linearity from DC bias

Ishaan Govindarajan

Sheet: /Reconstruction Filter/

File: modamp_Recon.kicad_sch

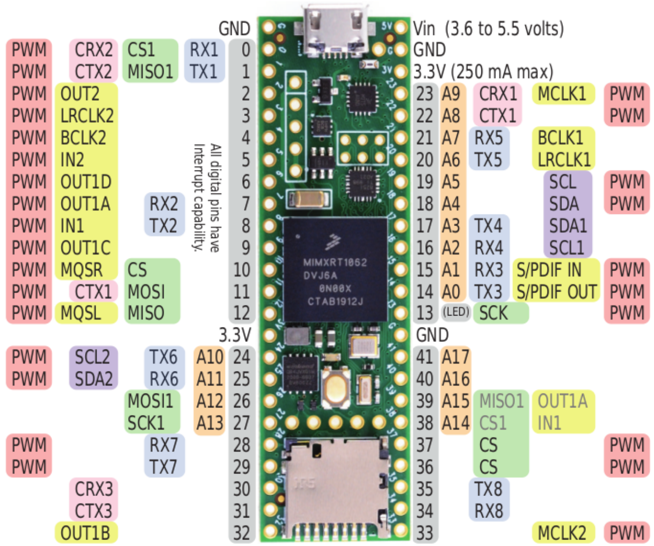
Title: Digital Audio Effects Processor

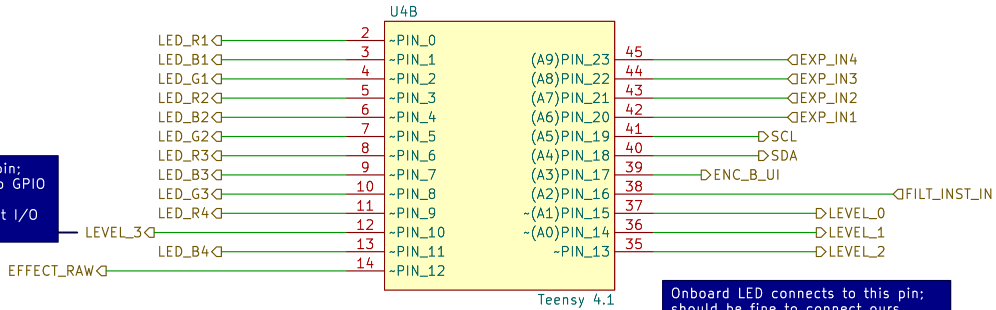
Size: A4	Date: 2023–11–26	**Rev: A**
KiCad E.D.A. kicad 7.0.5		Id: 6/14

MCU power handled in a separate sheet

Most pins on the MCU are mapped out of convenience, EXCEPT FOT THE FOLLOWING:

- P16 (A2) --> Instrument input (default mapped here)
- P12 --> DSP output (MQSL)
- P10 --> BE WARY, don't use for critical functionality
  (MQSR, may be able to be remapped)
- P13 --> onboard LED; needs to be mapped to an output

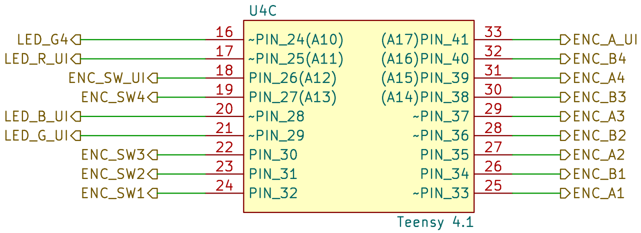




NOTE: This is the MQS_R pin; may be able to re-map to GPIO

Mapping to least important I/O for now

Onboard LED connects to this pin; should be fine to connect ours since our polarity is inverted



Ishaan Govindarajan

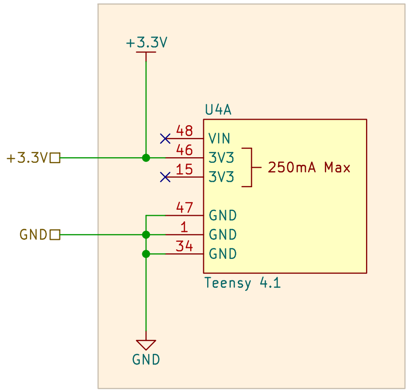
Sheet: /MCU/

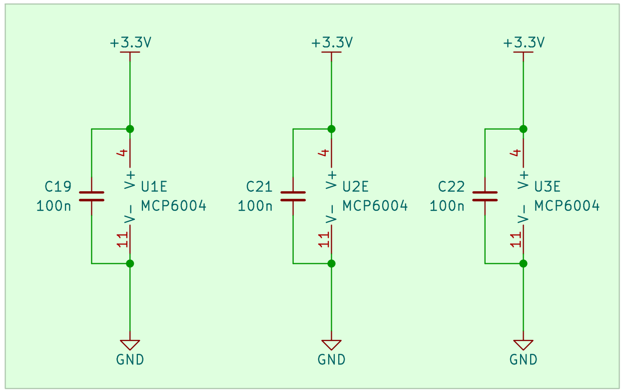
File: modamp_MCU.kicad_sch

Title: Digital Audio Effects Processor

Size: A4	Date: 2023-11-26	Rev: A
KiCad E.D.A. kicad 7.0.5		Id: 7/14

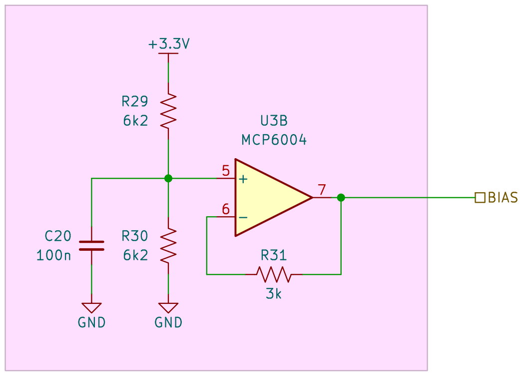
Power supplies for the quad op-amps; bypassing with a capacitor as well





Not connecting one of the +3.3V pins of the MCU since it's difficult on the PCB; not necessary to connect the +3.3V pins outside of the MCU

MCU has built-in power supply bypassing, so not adding extra bypassing externally



Generate a virtual midpoint reference for all of our analog circuitry; this is treated as "zero-reference"

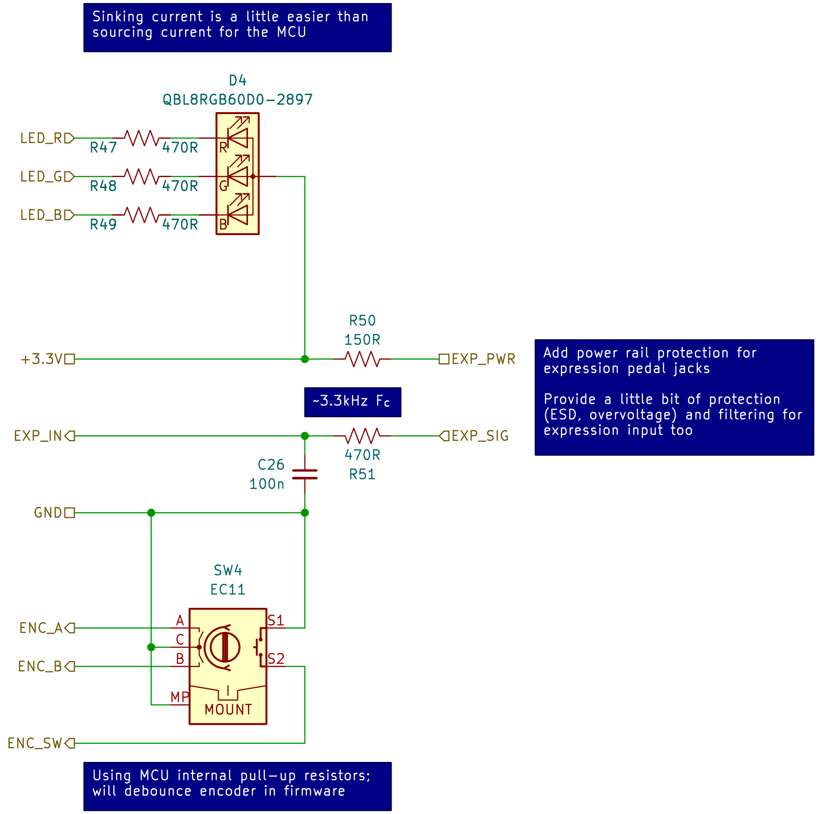
Ishaan Govindarajan

Sheet: /Power Supplies/

File: modamp_supplies.kicad_sch

Title: Digital Audio Effects Processor

Size: A4	Date: 2023-11-26	**Rev: A**
KiCad E.D.A. kicad 7.0.5		Id: 8/14

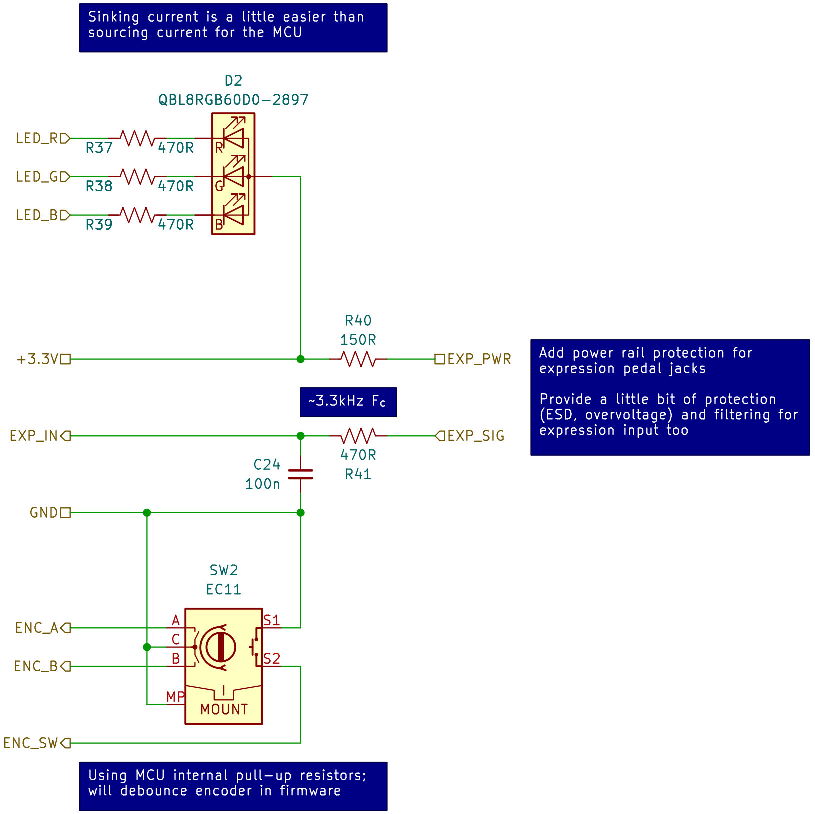


Ishaan Govindarajan

Sheet: /Effect Channel 1/
File: modamp_Channel.kicad_sch

Title: Digital Audio Effects Processor

Size: A4	Date: 2023-11-26	**Rev: A**
KiCad E.D.A. kicad 7.0.5		Id: 9/14



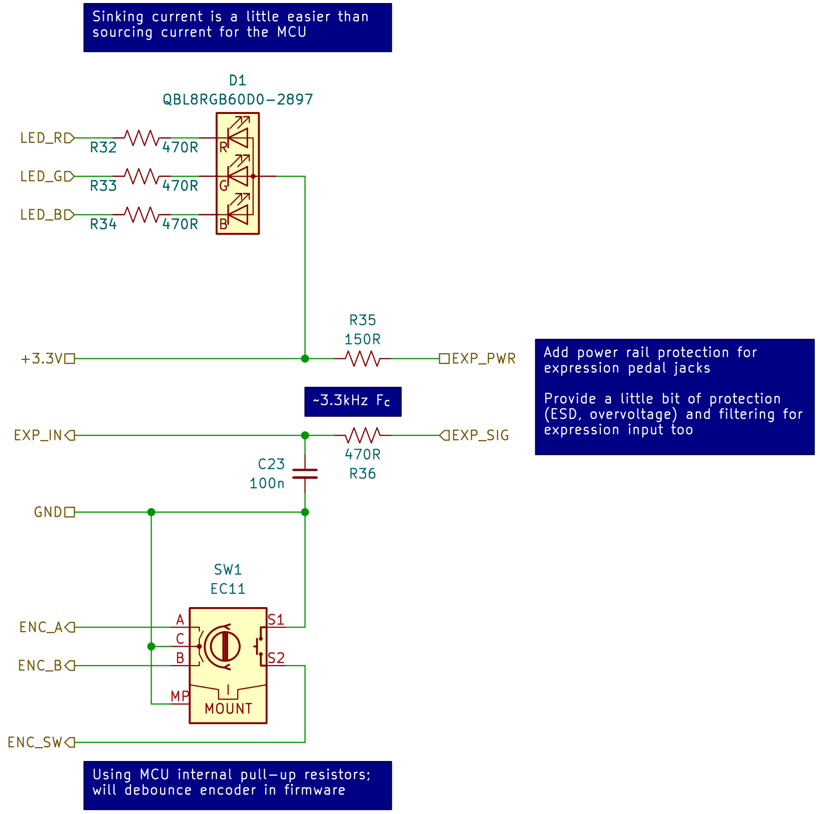
Ishaan Govindarajan

Sheet: /Effect Channel 2/

File: modamp_Channel.kicad_sch

Title: Digital Audio Effects Processor

Size: A4	Date: 2023-11-26	**Rev: A**
KiCad E.D.A. kicad 7.0.5		Id: 10/14



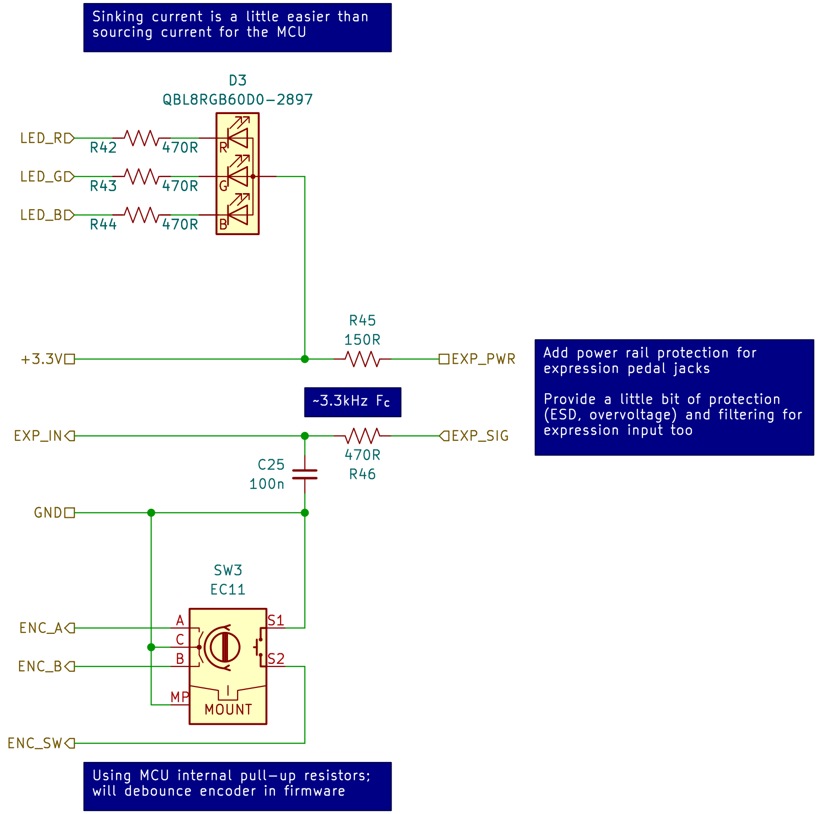
Ishaan Govindarajan

Sheet: /Effect Channel 3/

File: modamp_Channel.kicad_sch

Title: Digital Audio Effects Processor

Size: A4	Date: 2023-11-26	**Rev: A**
KiCad E.D.A. kicad 7.0.5		Id: 11/14



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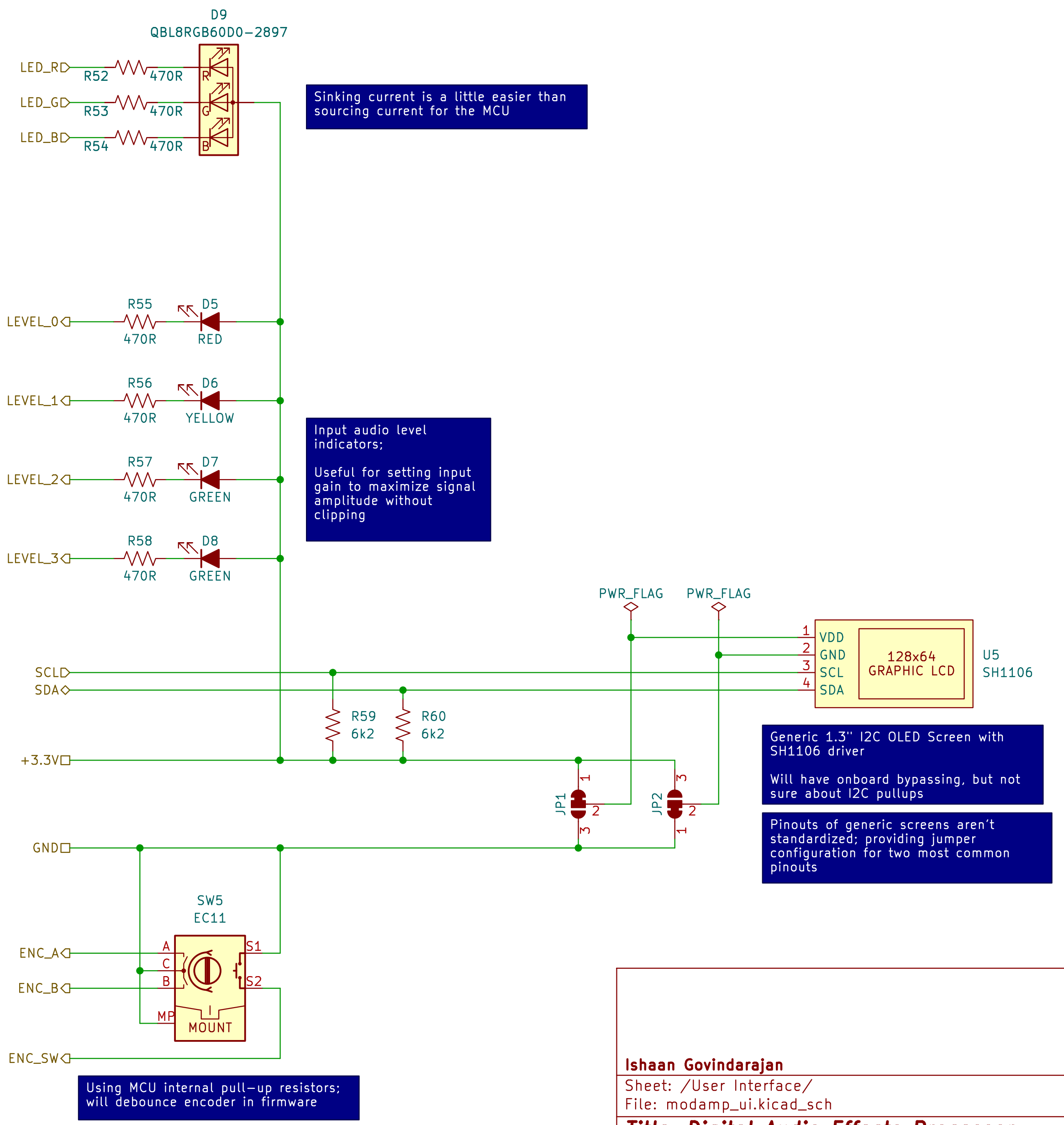
Sheet: /Effect Channel 4/
File: modamp_Channel.kicad_sch

Title: Digital Audio Effects Processor

Size: A4 | Date: 2023-11-26 | **Rev: A**

KiCad E.D.A. kicad 7.0.5 | Id: 12/14



Ishaan Govindarajan

Sheet: /User Interface/

File: modamp_ui.kicad_sch

Title: Digital Audio Effects Processor

Size: A4	Date: 2023-11-26	**Rev: A**
KiCad E.D.A. kicad 7.0.5		Id: 13/14

Component Selection

I designed this amplifier to help teach the basics of digital signal processing. As a result, the design aims to be easy to assemble (read: through-hole components) and primarily constructed out of cheap, readily-available components.

The main active analog component used in the design was an MCP6004 quad op-amp. Generally, any kinda rail-to-rail input/output, >600kHz GBP, and <0.1% THD+N parts should do the trick here. Suitable replacements include the MCP6294, LMC6484, TLV2464, and TLV2474 among other more expensive options.

The Teensy 4.1 was chosen as the main DSP MCU due to its pretty decent computational power, relatively low cost, great community support, ease of firmware implementation, and use in other classes taught at MIT.

I'm intending for a generic 1.3" Monochrome OLED screen with an SH1106 controller to be used as a display. These are pretty cheap (<$2 USD!) to acquire from east Asian retailers. Ensure that the hole pattern roughly matches, the pinout is acceptable (two possible options), and that the display runs an SH1106 controller.

Resistors, capacitors, and LEDs were chosen to be those commonly available in university electronics labs. Use of 1% or better resistors and <5% film capacitors will yield the most consistent performance. Lower tolerance components and different capacitor technologies may yield suitable performance, but no guarantees are made. Ensure that common-anode RGB LEDs are used!

Regarding poteniometers, encoders, and jacks, parts with common footprints were used. Any EC11-style encoder should work with the design, and are available cheaply from east Asian retailers. "RV09-sytle" potentiometers can be similarly sourced cheaply. The exact same thing can be said for "PJ-307-style" 3.5mm TRS jacks, and "PJ-609-style" 1/4" TRS jacks.

General Design Notes

Hi! I'll try to capture some details about certain design decisions in this section of the schematic. If I miss anything, let me know and I'll update this section!

Overall System Architecture

A modelling amplifier has the benefit of offloading a good deal of hardware signal chain elements for those performed in firmware. As such, the only real thing that needs to happen on this amplifier is biasing, pre-amplification, filtering (anti-aliasing and reconstruction), volume control, and "de-biasing". You'll see all of these functions replicated in the signal path on the top-level schematic.

In addition to these, I've found a general-purpose line-level input useful when jamming/practicing by myself. This allows you to play along with backing tracks or songs from a PC or phone. I've included a line-level input in this design that gets mixed (summed) with the effect output to allow this functionality too.

Aside from the forward signal path, I've included four expression pedal inputs (on/off or analog) to modulate effects. These are interfaced with a TRS jack to an external stomp switch or treadle potentiometer. Hardware/firmware implementation of this is relatively flexible, so have some degrees of freedom with overall implementation.

Five rotary encoders and RGB LEDs, and a small screen form the user interface. I'll go into the details of the implementation in the "User Interface Ideas" section. Four LEDs also visualize the input signal level to help set an appropriate pre-amp level.

User Interface Concept

The primary user input device to the effects processor will be the five clickable rotary encoders. At the top level, four of the encoders (and expression pedals) will provide "quick edits" to four possible effects channel, and a fifth "main" encoder to cycle through menu options.

When one of the "effects encoders" are clicked, it will allow editing of five different parameters of the selected effect. A clicked encoder will bring the UI back to the main menu, and the selected effect will corresond to the "quick edit" paramter available at the top level.

The general idea regarding the user interface has evolved while drafting this schematic. This is why schematic is organized slightly differently than the UI.

Design Tradeoffs

Often in this design, performance vs cost/ease of assembly had to be traded off. A proper I2S audio CODEC would have significantly improved the performance of this ampifier, but would have gone against core philosophies of hand-assemble-able, through-hole design. Therefore, discrete op-amps and MCU peripherals were used to digitize and reconstruct the audio. As a byproduct, this approach lends well to discussions about high-order filter design, oversampling, dither, and noise-shaping.

I also spent a bit of time debating about a mono vs. stereo output. A stereo output would have yielded the possibility of some really cool effects. However, a mono design reduces component count, simplifies component sourcing (no fancy dual-gang potentiometers), reduces board space, and requires slightly less computational power. I/O limitations (all easily-accessible I/O of the MCU is being used!) would mean a stereo implementation would be difficult. For these reasons, I've implemented effects in mono.

Ishaan Govindarajan

Sheet: /Design Notes/
File: modamp_DesignNotes.kicad_sch

Title: Digital Audio Effects Processor

Size: A4	Date: 2023-11-26	**Rev: A**
KiCad E.D.A. kicad 7.0.5		Id: 14/14