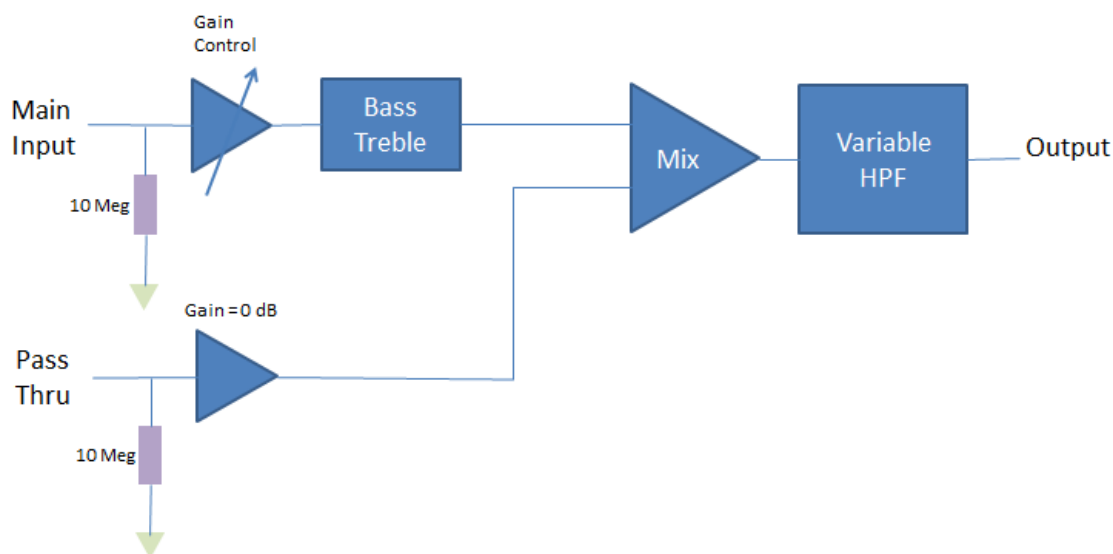


Channel Two Preamp - v1

November 2, 2024

Francis Deck, November 2, 2024



Channel Two is a general purpose preamp for musical instruments. I designed it to add a second input channel to a perfectly good bass amp, for gigs that require me to “double” on upright and electric bass. It has two inputs:

1. **Main channel** has gain, bass, and treble controls. These are hopefully enough to compensate for differences in volume and EQ between two instruments, and to support use as a general purpose preamp. Gain is from 0 to 10, i.e., +20 dB.
2. **Pass-through channel** has fixed 0 dB gain and no controls.

Both channels have 10 MegOhm input impedance, compatible with most instrument-level signals, including piezo upright bass pickups.

The two channels are mixed together, and fed through an adjustable high-pass filter, identical to my **HPF-Pre Series 3** design.

The circuit requires DC or battery power, nominally 9 to 30 V.

How you use **Channel Two** depends on how your amp works, and your imagination. Optimally, it can be plugged into the Effects Loop of an amplifier, or its output can be plugged into an “Aux” input. If those connections are not available, then it can also be inserted into the signal input of the amp, though this makes adjustment of the controls just a bit more complicated.

Other uses include providing a spare channel if someone's amp breaks, or if a microphone is needed for announcements and the Best Man's speech.

Why not use a two-channel amp? There are very few of them on the market, and they tend to be much more powerful than what I need. And then I wouldn't be able to have this fun project! And even with a two-channel amp, I still need to bring a box, because most amps don't have the variable HPF that I want. I've drunk my own kool-aid on HPF's.

Why not use a mixer? A mixer requires *multiple* extra boxes, because most of them don't have high input impedance, needed for my piezo pickup, or variable HPF. The Channel Two preamp is a type of specialized mixer, but because it's my own design, I can cram all of the other stuff that I need into just one box.

1 Open source information

This project is offered in the spirit of "open source," meaning that I'm sharing all of my documentation, and you can make one of these yourself. You can also modify the design to suit your needs. Unfortunately, I'm using an outdated printed circuit layout program, meaning that modification will be possible but challenging. I just haven't kept up with progress in electronic design automation tools for my home business, and have done OK because my boards tend to be extremely simple.

I'm thinking about whether I want to commercialize this design. If I do, I will continue to maintain and update this repository.

This repository includes so-called "Gerber" files that are needed for having boards fabricated by suppliers like JLCPCB or PCBWay. I don't sell boards, but you'll see that the prices at these vendors are extremely cheap, even despite the minimum order quantity (typically 5 units), and it doesn't make sense for me to be a middleman.

Advanced skills will be needed to build this project yourself, for two reasons. First, the surface mount op amps are in TSSOP package, which are difficult to solder. I switched to TSSOP for my products during the chip shortage. You'll need good soldering equipment and a magnifier to confirm that you haven't bridged any adjacent pins with solder. Second, due to the complexity of the circuit, troubleshooting will be difficult if it doesn't work on the first try, and at the very least you will probably need a voltmeter if not an oscilloscope.

Components are all general purpose, except the potentiometers, which are specific Taiwan Alpha parts. You might be able to find substitutes, but I chose these pots because I have a long history with them, and am satisfied with their quality and reliability.

Warning about documentation: Computer programmers have recognized this problem, which is that the documentation doesn't keep up with changes to the design. I will make sure that the Gerber files are the ones that I've used to build a working prototype, but I have no guarantee other than checking things carefully, that the schematics and other documentation match the Gerber files precisely.

Here's my take on surface mount: I've migrated my business to surface-mount designs. Older designs will continue to use through-hole parts, since I have a generous inventory, and "if it ain't broke, don't fix it." However, it's getting harder to find through-hole parts, in small quantities, from manufacturers and distributors that I trust. I have a feeling that some of the distributors used the pandemic as a chance to trim obsolete parts from their catalogs.

I was already using surface-mount op amps, in SOIC packages, and those absolutely disappeared during the pandemic. Just to fill orders, I had to re-design my boards for the TSSOP package, and get good at soldering it.

Repair requires surface-mount skill, but it can be learned. I'm not worried about the IC's. In the entire lifespan of my business, I've never had an HPF-Pre come back with a failed op amp.

2 Cautionary statement

I am not an engineer. This design has not been approved by any engineer or regulatory body. It should not be used under conditions where its failure – either due to design or construction – could result in a hazardous condition. This design, as documented here, does not include a safety enclosure.

3 Files

The repository is just a dump of my working directory for this project. To aid the reader, I've taken screen shots of the important graphics, so you don't need to install your own software unless you want to make changes.

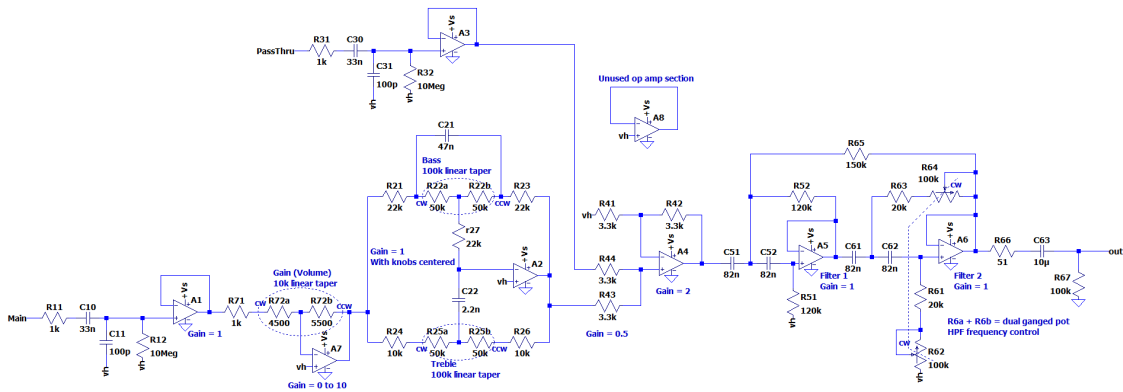
Because this is my working directory, there's a lot of stuff that's not worth looking at unless you're planning on changing the design. For the most part, you need this PDF, and the zip file containing the Gerbers.

4 Schematic

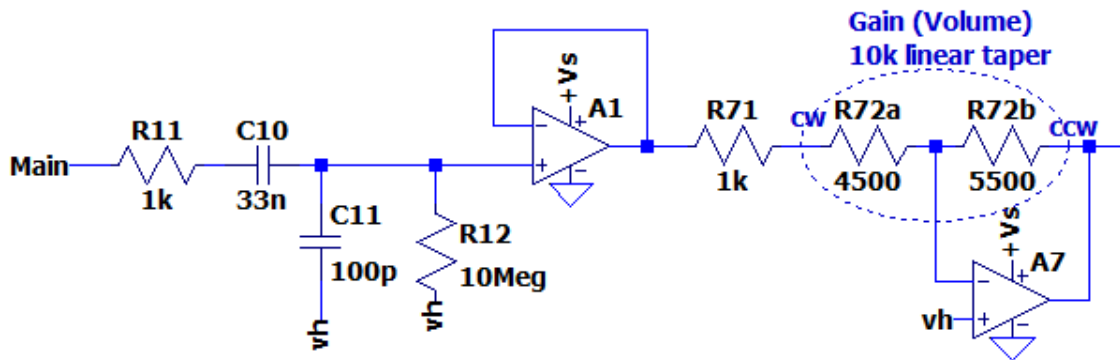
Here's the full schematic. Don't try to read it on a small screen. I'll be breaking it up into sections below.

The first thing to notice is that this is a single-supply circuit, meaning that there is a single positive power supply voltage. Most single supply audio circuits work by providing a “virtual ground” which is a clean voltage, half of the main power supply voltage. This is labelled “vg” throughout the circuit. When comparing this circuit to textbook designs, treat “vg” as “ground.”

Gain staging is going to be important for this preamp, because a strong signal could produce clipping if additional gain is applied. Bass signals – electric and upright – are right in that zone where you don't want a lot of additional gain in a battery powered box. For this reason, the circuit by default has no insertion gain in the pass-through channel, and can be set to a low gain level in the main channel. On the other hand, the lack of high input gain means that noise levels have to be managed throughout the signal chain. For this reason, I'm using an op amp chip with a very low noise level, which would be considered “overkill” in a mainstream bass amp. My text mentions some other op amp choices.



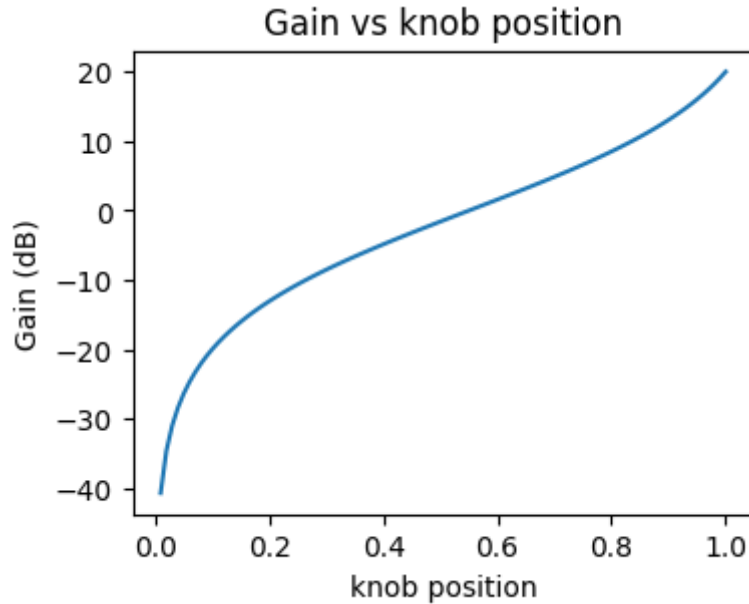
4.1 Main input gain stage



The main channel needs a gain control, because the two instruments might not have the same signal levels. I might need more gain, or less. For instance my electric bass produces a weaker signal than my upright bass.

The input signal is passed through a DC blocking capacitor C10 – typical for a single supply circuit. Series resistor R11 provides just a bit of protection to the op amp in case of an overload signal, and C11 filters out stray RF interference. This might seem like a lot of capacitance, but most instrument cables are about 50 pF per foot.

Potentiometer R27 controls the gain of a classic “inverting amplifier” stage. The gain is $R72b / (R72a + R71)$. Thus, it can be turned all the way down to zero, like a volume control. This is my way of avoiding the need for separate gain and master volume knobs. The curve of gain versus pot rotation looks like this:



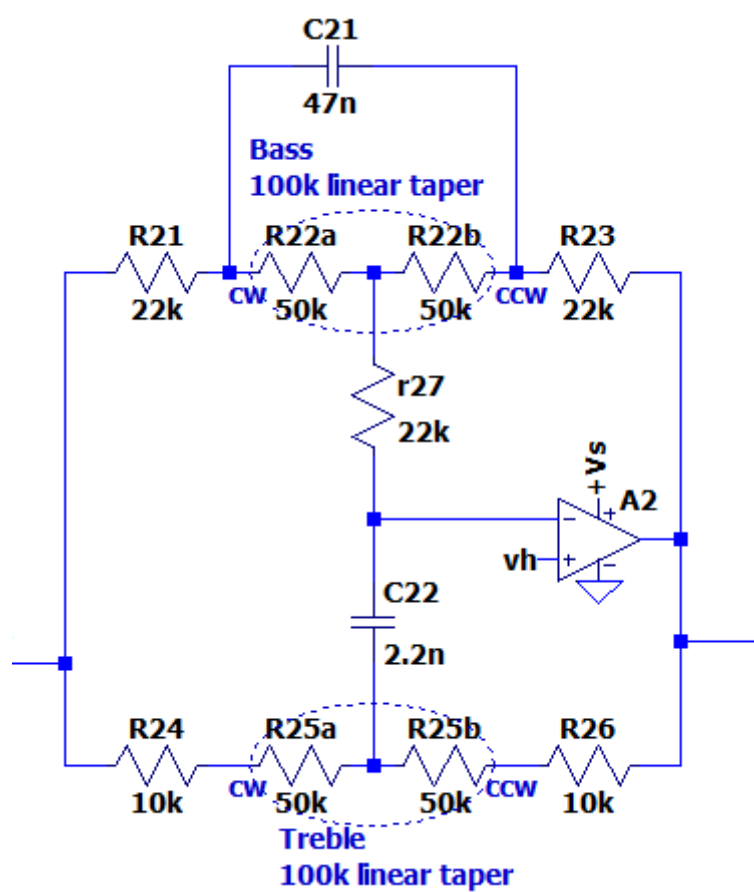
Ideally, the curve would be a straight line, but making that happen requires a special pot that might not exist. A realistic goal is to be linear enough to have a usable control response. The curve provides the ability to boost or cut the input signal, including a small portion of the range where the signal can be shut off entirely, like a volume control.

You can play with the pot and resistor values if you need more gain. That might be needed in an odd case where a bass or pickup is producing a particularly weak signal. But I think that most electric and upright bass pickups are – by design – close enough to a nebulous “instrument level” that the control range shown here should be sufficient.

4.2 Tone control stage

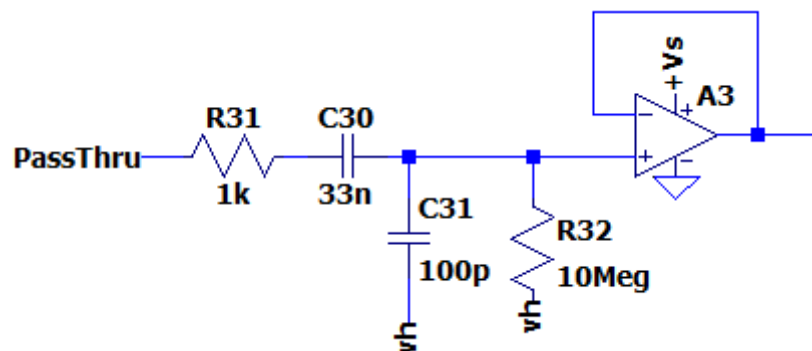
This is a classic Baxandall circuit, from a classic website that’s worth reading:

<https://sound-au.com/dwopa2.htm>



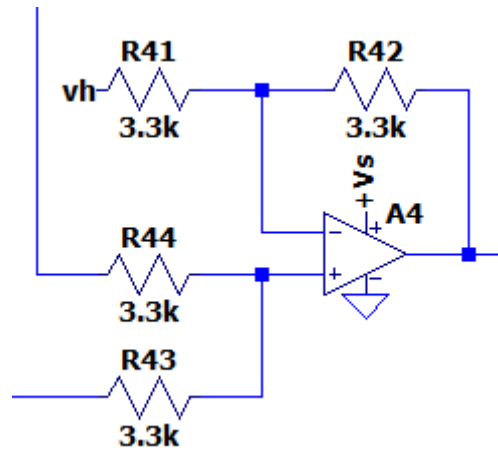
I've played a bit with the component values, since a very high frequency treble control isn't of much use for most musical instruments, including bass.

4.3 Pass-through buffer stage



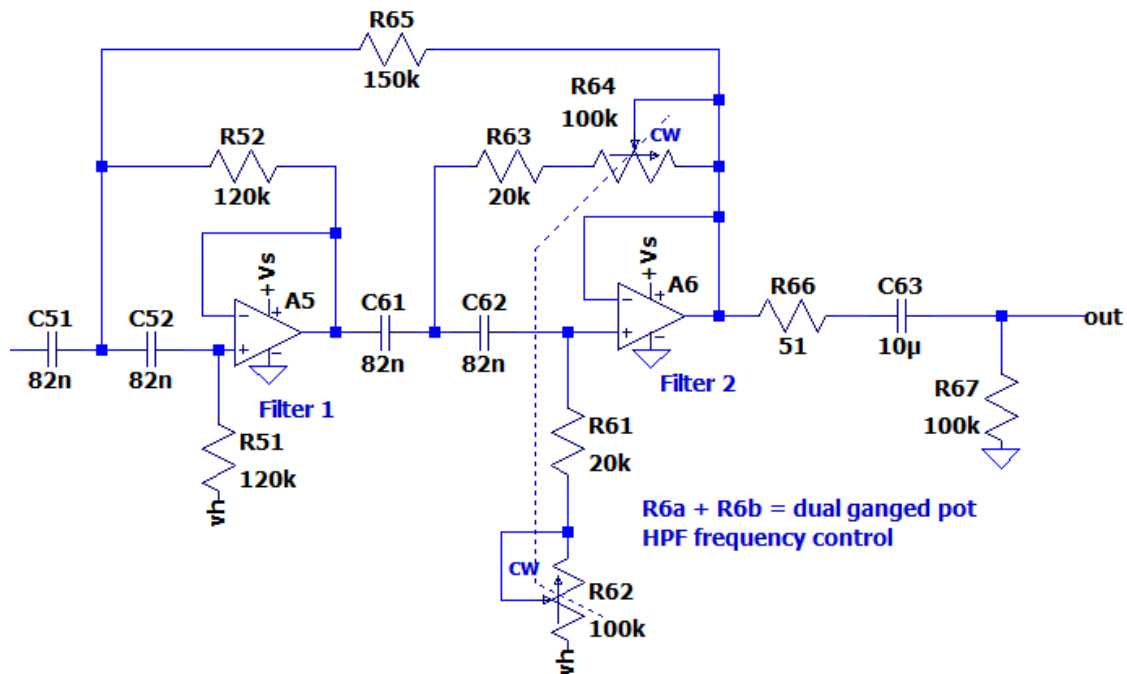
A buffer is needed to provide a high input impedance, in case you choose to use this input with a piezo pickup. This buffer is identical to the buffer for the main input.

4.4 Mixer stage



The input gain stage and the Baxandall tone control both have negative gain, so they have an overall positive gain. I want the circuit to preserve the phase of the input signals. So the summing circuit needs to have positive gain for both channels. R43 and R44 produce an average of the input signals and then applies 2x gain. The result is a pure sum of the signals with no additional gain.

4.5 Variable high pass filter stage



This circuit is identical to the filter in my HPF-Pre “Series 3” products. There are two Sallen-Key high pass filters. The first has a fixed corner frequency. The second is variable. When the frequency knob is at its lowest setting, the two filters work together to form a single high pass filter with a

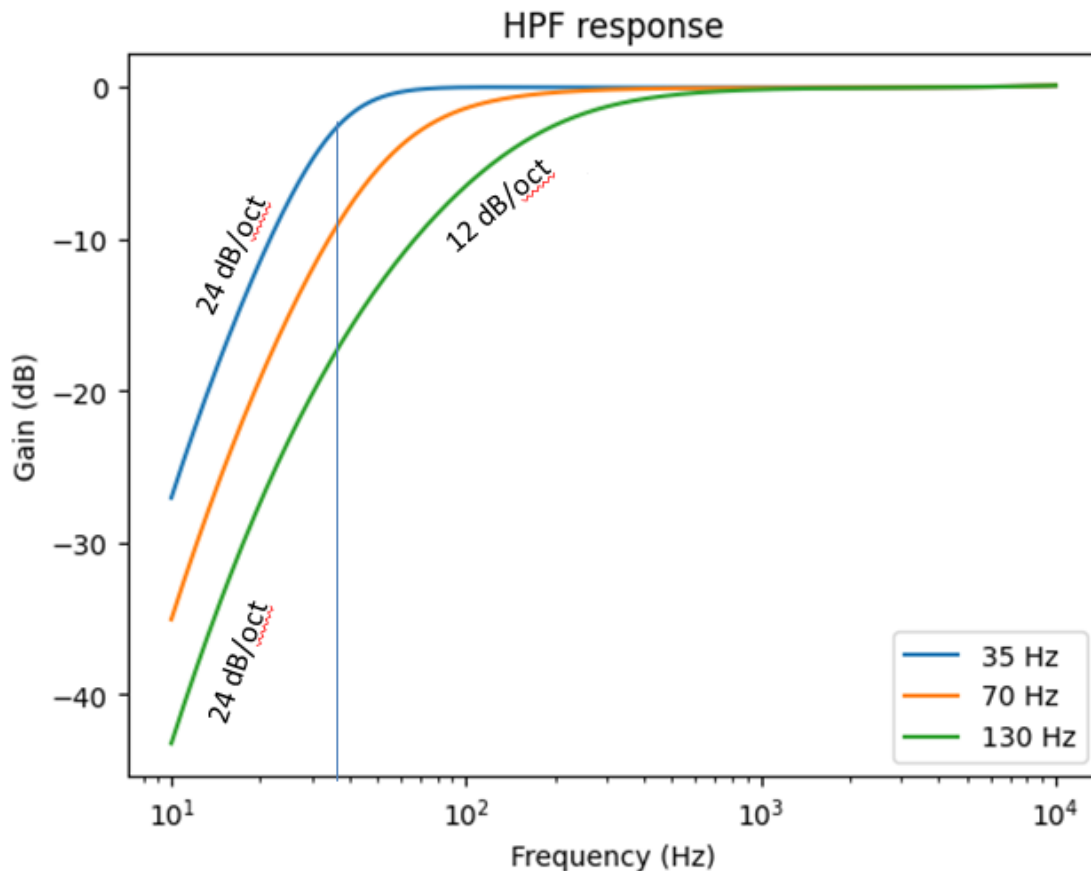
35 Hz corner and 24 dB per octave slope. Turning the knob raises the corner of the second filter, resulting in two slopes: Roughly 12 dB/octave down to 35 Hz, and 24 dB/octave below 35.

It's a highly effective, and musical, filter. The hard cutoff below 35 Hz helps manage some of the newer “super” cabinets being driven at high power, and the more gentle curve above 35 Hz makes it a useful control for managing things like the acoustics of small rooms.

This design idea came to me in discussions with some people who contacted me about making a version of my HPF with a 24 dB/octave slope. Chaining two variable filters would have required a pot with 4 gangs, something that I didn't relish trying to buy. And I thought that such a filter would produce quite a loss of bass if the knob were ever moved from the lowest cutoff frequency. Instead, I came up with the idea of chaining two filters, but making only one of them variable.

Both stages are the traditional Sallen-Key filter design with equal capacitor and resistor values. The op amps have gain of 1. Normally, this would produce a “soft knee” at the cutoff frequency, the so called “bessel” response. I prefer the “butterworth” curve, which is optimally flat until it reaches the cutoff transition. This requires adding gain to the op amp, but see above about gain staging. I don't want any unnecessary gain. I discovered my “magic resistor,” shown as R65.

Here's how the response curves work on the “Series 3” filter, taken from the LTSpice model:



5 More design details

5.1 Op amp choice

There's just a bewildering proliferation of op amps out there. Many general-purpose types will work OK in this circuit. The most important criteria are:

1. Must be available in a quad TSSOP-14 package.
2. Must be JFET or CMOS type, because my circuits don't correct for bias current.

For my HPF-Pre Series 3 products, I use Texas Instruments (formerly Burr Brown) OPA1654, which is designed for audio use, with uncompromising performance and a wide power supply voltage range. However, it's expensive, and consumes 2 mA per channel, adding up to 16 mA for this circuit. Battery life will not be stellar. Its input noise is 4.5 nV per square root of Hz (nV/rtHz). Quieter op amps tend to be bipolar types, which can't be used in this circuit.

For 9-V battery operation, I've had good success with an old CMOS op amp from Texas Instruments, TLC2264. Op amps face a tradeoff between supply current and noise performance, but the TLC2264 draws 0.5 mA per channel while having an OK noise spec. It's a "rail to rail" op amp, meaning that its output can reach both power supply rails. *I believe this op amp must be used with great caution if powered from a wall wart, see below.* Its input noise is 12 nV/rtHz, roughly 9 dB above the OPA1654. The difference may be inaudible for most uses.

The generic TL074 would be an acceptable substitute. It's ubiquitous in commercial bass amps for many good reasons. First, its noise performance is not state-of-the-art, but is probably below the noise floor of most electric bass pickup systems. Second, it's a generic part, meaning that there are multiple suppliers, which greatly reduces supply chain risk. Imagine my surprise when my beloved OPA1654 chip became unavailable during the pandemic. The Texas Instruments version of the TL074 cites an input noise of 19 nV/rtHz, roughly 13 dB above the OPA1654. This might seem bad, but you have to consider it in the context of its actual use. Your bass amp is probably already chock full of TL07x op amps.

5.2 Component selection

Some of my component choices are driven by my product line, which has its own history. If this thing ever becomes a product, I want to re-use parts that are already in other designs.

All passives are 0805 surface mount, general purpose types, except for the four 82 nF capacitors in the HPF circuit. Those are film caps with 5% tolerance. The pots are Taiwan Alpha. I have a long history with those pots, and they've held up well in my products. You'll notice that my layout accommodates dual ganged pots, but only the HPF needs one. You can use single or dual pots in the other places.

I don't see the point to providing part numbers for the passives because things go in and out of availability, even at the big distributors. Resistors should be 1%. No sense in adding more variability than needed. Working voltage of caps should be at least 35 V. I've learned to use OctoPart for buying passives, while checking a single distributor to minimize shipping costs.

5.3 Power options

I see an interesting "culture" difference here, based on my product mix, and talking to bassists. Upright players tend to prefer battery operation. I think that battery powered gadgets reduce the

amount of cabling needed at a gig. For instance, all I need is a power cable for my amp, and I don't even bring an outlet strip. And battery life is tolerable given that I don't use an amp at all when practicing at home.

Electric players tend to prefer a power supply. I think most electric players are already providing power to multiple things, and are using their powered gear at home as well as on stage, so a device that doesn't need batteries seems simpler in this case. When my HPF-Pre products were "discovered" by electric bassists, the first thing they asked for was a power jack.

Unregulated power supplies produce much more than their rated output voltage. **Watch out!** These are typically the old line-frequency supplies, that are heavy and big. I have one, rated at 9 V and 350 mA. Under no load, its output measures 16 V. Why? The rating is the minimum guaranteed voltage, accounting for variations in mains voltage and load current. When plugged into clean household power, and with minimal load, the output voltage is much higher than the rating.

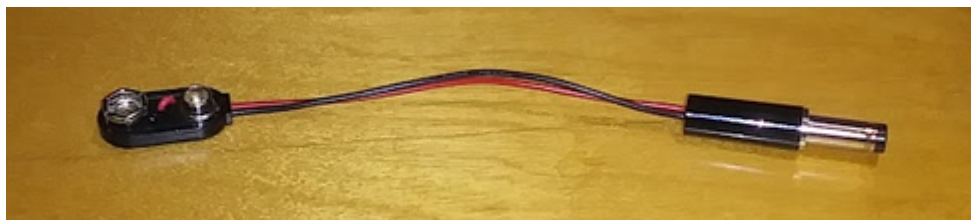
Running at 16 V would be just fine for the OPA165x or TL07x op amps. It would be in danger of killing the TLC226x op amp chip. A semiconductor engineer once told me that the absolute maximum voltage ratings on ICs has no margin for error, because it's designed into the fabrication process for the chip.

There are trends towards higher power supply voltages in the bass world, with some players preferring 18 or even 24 V. **Watch out!** Given my measurement of the 9-V wall wart, a 24-V unregulated wall wart could put out as much as 43 V, which is beyond the ratings of virtually all op amps.

Regulated power supplies put out their rated voltage, within much tighter margins. These tend to be the newer, lightweight ones. I think some regions (possibly California) are encouraging the phase-out of the old line-frequency wall warts because their idle current is not insubstantial, and there are a lot of them out there.

Do we need more than 9 Volts? Here's my opinion. I think that the trend towards higher voltages in the signal chain for musical instrument gear is a bad idea. Even if operating within the limits of a 9-V battery, there's plenty of dynamic range. Since most active circuits draw constant current independent of supply voltage, doubling the voltage means throwing away two batteries instead of one. The amp can handle the transition from instrument level to speaker level. But since there are now lots of 18-V systems out there, we have to provide compatible gear if needed. I'm OK with that, but 9 V suffices for my needs.

Emergency back-up generator



6 Construction

I use Kester K100 solder alloy. It's a lead-free alloy with fairly good properties. It melts at a lower temperature than the first generation lead-free alloys. I also order lead-free boards by specifying

“lead free HASL” surface coating.

I have different practices for “first time build” and for “production.” I suggest treating this as a first time build, even if you’re confident in your construction skills. I populate the board, stage by stage, and test each stage before moving on to the next one.

Start with the power supply wiring. The power input passes through a Schottky diode, which has a forward voltage of about 0.25 V, so the main supply voltage V_s will be lower than the power input voltage by that amount. The virtual ground V_h will be close to half of that value.

It helps a lot to have a signal generator and oscilloscope for tracing the signal through the circuit, but it can be done without a scope. If you don’t have a scope, you can trace your way through a circuit by connecting a wire to a jack, and using it as a probe, going through an amp with the volume turned way down. Because the signals are based at half of the supply voltage, there will be a “pop” every time you connect the wire.

Make sure each stage works as expected before moving on to the next stage. This will minimize the amount of stuff you have to throw away if troubleshooting ends up damaging something.

The IC packages are tiny! This is where you’ll need some soldering technique. Here’s what works for me. First, I work under a magnifier. I apply a tiny blob of solder to exactly one of the circuit board pads. Then I hold the IC in good alignment with a tweezers (check pin 1 orientation) and heat that blob. The IC will now be held in place by one pin. Make sure it’s laying all the way down on the board.

Next, I solder the rest of the pins, starting at the opposite corner. On occasion I will make a “bridge” of solder between two pins. I use my soldering iron and solder wick to suck up the excess. The result is usually a good joint. View it from above and from the side with good magnification and lighting. I have a stereoscopic inspection microscope that I use for this purpose.

For the 0805’s, I lay a blob of solder onto just one of the two pads for each part. Then I hold the part with tweezers, melt the blob, and lay it down. With all of the parts in place, I turn the board around and solder the other end of each part.

6.1 Parts availability

The only specialized parts are the pots, and pots are a pain in the neck: Finding high quality pots with the right mounting features and the needed values is always hit or miss. I’ve resorted to dual pots even though three of them could be single, just because they’re all available from the same supplier.

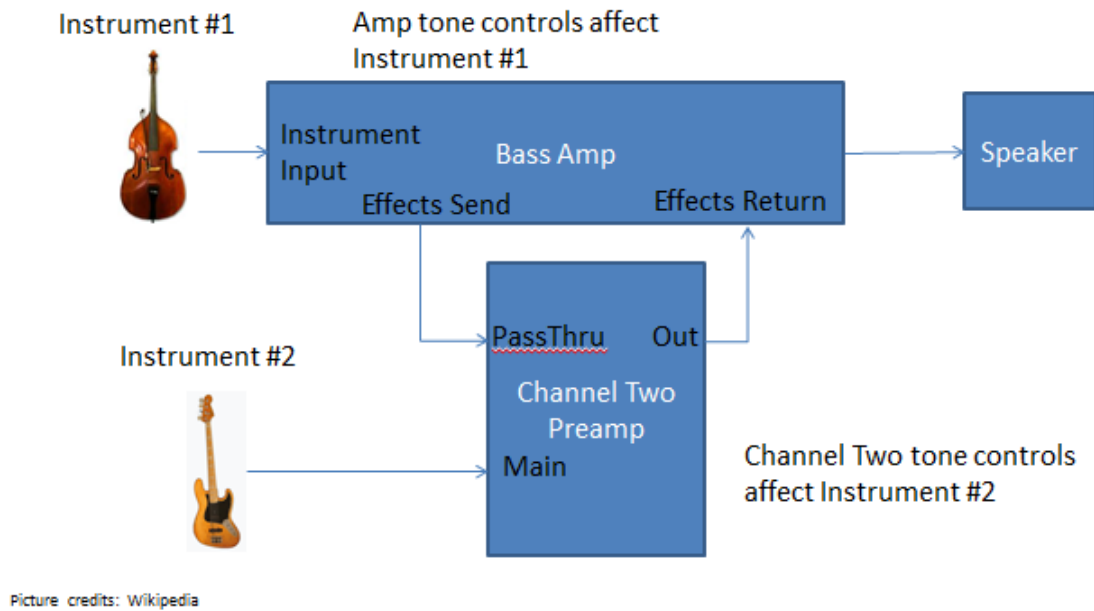
The commercial makers order custom pots from the factory, or at least get a guaranteed supply line on standard offerings. I don’t want to buy 5000 of anything.

Designator	Part	Mouser Part #	Note
R15	10k linear taper pot	31CN401-F	Single version not available
R22	100k linear taper pot	313-1250F-100K	Single version not available
R25	100k linear taper pot	313-1250F-100K	Single version not available
R52 + R53	100k dual audio taper pot	313-1240F-100K	

7 Setup and use

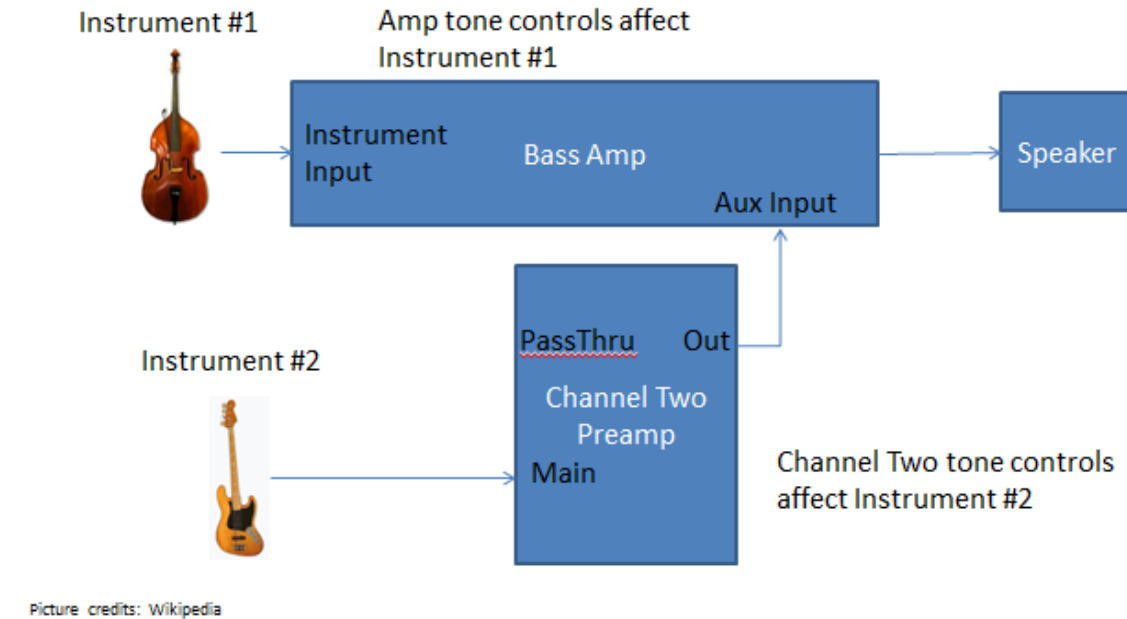
Some amps are more friendly to the Channel Two preamp than others. An amp with an “Effects Loop” can be hooked up with two patch cables:

Amps with effects loop



If the amp has an “Aux” input, consider this setup:

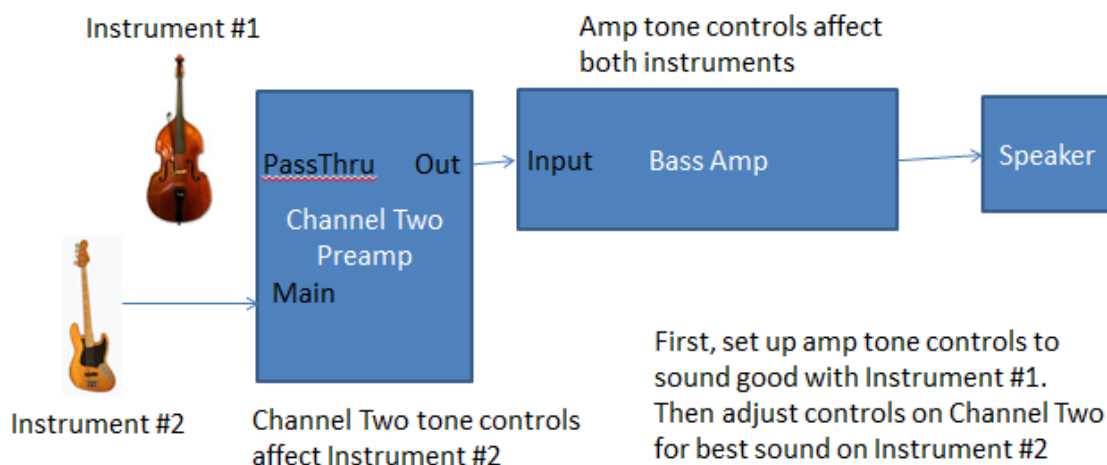
Amps with “Aux” input



If there are no additional jacks on the amp, then you can insert the Channel Two preamp directly into the main signal path.

In this setup, the tone controls of your amp will affect both instruments. You can use the controls on Channel Two to make up for differences in the two instruments.

Amps without additional jacks



Picture credits: Wikipedia

8 Planned upgrades

8.1 “Active diode” for voltage reversal protection

The Schottky diode is a convenient way to protect the circuit from damage if the power supply is reversed, but does lower the supply voltage by a bit. I found this cool circuit, an “active diode” for protection:

<https://hackaday.com/2011/12/06/reverse-voltage-protection-with-a-p-fet/>

It works by using a P-type MOSFET as a switch. When the supply voltage is above a threshold, the MOSFET is turned on, and has a forward resistance of about 0.1 Ohms, so the voltage drop across it will be a couple of mV.

Stay tuned. When I make this mod, I will upgrade the circuit board design. In the meantime, the Schottky diode does work well enough.

```
[1]: # This cell converts the notebook to a PDF file
      # Save the file first
      !jupyter nbconvert --to pdf "Channel Two Preamp.ipynb"
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