BBBB - Bare Bones Bass Blender 10/1/2005

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Files

BBBB Baxandall.asc	Simulation of Baxandall tone control circuit, using SWCAD program, available for free from Linear Technology. (http://www.linear.com/company/software.jsp)
BBBB Main.asc	Complete BBBB circuit, using SWCAD as a drawing program
BBBB Parametric.asc	Simulation of the parametric EQ.
BBBB.pcb	Printed circuit file, using ExpressPCB program (www.expresspcb.com)
BBBB picture.jpg	Photo of my build of the BBB
Schematic.jpg	Picture of the BBBB schematic, in case you don't want to download SWCAD.
*.asy	Custom part definitions for SWCAD
*.asc	Other goodies and freebies, as I find them on my hard disk.
BBBB.doc	This document

Overview

Note that I will continue to update this document as my design evolves. This page describes my bass preamp design, with the following features:

- Two inputs, each with 1-MΩ impedance, gain control, and phase switch. Note to self: Need to test with 10-Meg input resistors.
- Mute switch, bass & treble EQ, and master volume.
- Balanced and unbalanced DI outputs.
- Flexible power options, including excellent headroom with single 9-V battery.
- Output level of 9 V peak-to-peak easily drives most power amps.
- Approx. -117 dBV noise floor, unweighted, 20 to 20k Hz.
- Approx. 0.01 % THD, 0.05% IMD.
- Freebie: Parametric EQ design, somewhat of a work in progress.

Why design yet another bass preamp? The reason was to have my choice of features, in a compact package, running on battery power with reasonable efficiency. So far, this preamp has worked flawlessly at numerous gigs, typically feeding the power amp input of my GK MB150E combo. I have used the preamp successfully with a homemade magnetic pickup, a K&K Bass Max piezo transducer, and an Ibanez passive electric bass.

The picture shown above is my second build of the preamp, in a cast aluminum box that I scavenged. The extra hole and notch are from a previous project. Not shown is the battery holder, held to the inside of the bottom cover by self-adhesive Velcro.

There are different schools of though on bass tone, which is why there will never be a one-size-fits-all bass / preamp / amp / speaker, etc. The BBBB circuit is designed to deliver "transparent" tone quality – flat response, low distortion, low noise. The tone curves are relatively subtle.

My preference for clean sound comes from working a huge variety of gig situations, often with no time for a sound check. It is crucial to have a totally predictable tone quality. Also, I tend to choose instruments, including electric basses, with a lot of acoustic character of their own. These seem to require less help in the tone department. I say these things with no lack of respect for other approaches, but just to help you decide whether this preamp meets your needs.

Before you go building this thing, please…

Don't do it unless you are insane. It is common knowledge that you don't save money building DIY gear, so forget about that. Don't be surprised if this project sets you back $100+ in parts, especially if you make the same number of mistakes that I did. The novice builder should not be tempted by the ease of stuffing parts into a printed circuit board. You are going to be up against a wall if it doesn't work on the first try. My first try involved diagnosing a problem related to a bad part, so it doesn't always go smoothly. I am not going to be able to provide debugging advice.

There are simpler, and more complicated, designs out there. It is worth searching the Web for a design that meets your needs, experience level, and desired construction technique. You can also mix and match design elements. Here are some of my findings:

http://www.cafewalter.com/cafewalter/rackpre/rackpre.htm -- Walter Harley's preamp, a nice design with tone shaping intended for electric bass. Also at this site is some useful information about the signal waveform from an electric bass.

http://www.jensen-transformers.com/as/as098.pdf -- Studio quality piezo preamp design, which can be used without the output transformer.

http://www.rane.com/ap13.html -- The Rane AP13 acoustic preamp. I shoplifted a design element from the published AP13 schematic, for use in the BBBB.

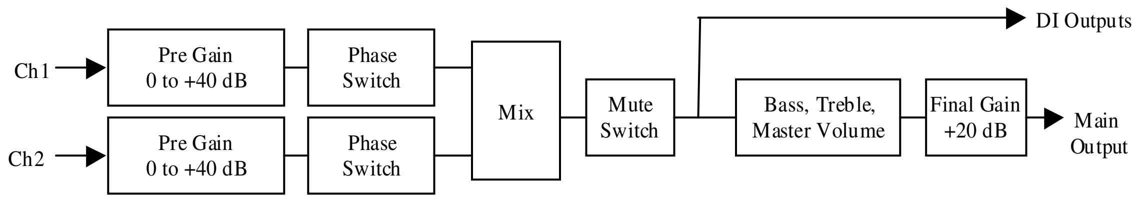
http://www.execpc.com/~fdeck/bass -- My website, where you can download all of the design data for this preamp, including the printed circuit CAD file.

http://www.diyaudio.com -- A forum devoted to DIY audio, including a discussion of musical instrument electronics.

Never overlook combining features of published designs. Most contemporary Fender bass amp schematics can be found online, as well as classics such as the Ampeg SVT. Some schematics can be bought. This stuff is largely un-patented, and if truth be told, very few of the ideas in these designs are particularly original. Remember that you can add or omit features as you desire. Have fun! Beware that you are responsible for the safety, accuracy, and reliability of anything you build based on this design. Please don't install this circuit in environments where dangerous high voltages may be present. Even the "phantom power" from a microphone mixer is a high enough voltage to be potentially dangerous.

Circuit description

The preamp circuit follows this block diagram:



The gains are high, because my magnetic pickup has fairly low output. Having some gain at the output stage allows for lower internal signal levels, thus providing more favorable headroom through the EQ section. Of course you can tamper with the gains by choosing resistor values, to match your basses. If you have really hot pickups, see below. There is even a way to pad a piezo pickup. The full schematic is shown in the schematic.jpg file.

Only minimal explanation is needed, since the circuit follows the block diagram. Most of the design elements are cookbook. The front end gain stage is borrowed from the Rane AP13 preamp, though there may be examples elsewhere. Having two gain stages avoids gain-bandwidth problems, and also results in a very smooth and linear control curve. The series resistor in the input is a CMOS trick -- it limits current through the op amp's internal protection diodes, thus allowing the circuit to survive rather severe overloads. The series resistors at the outputs provide an added margin of stability when driving long cables or capacitive loads.

Choosing op amps for battery operation proved to be a challenge. It's easy to be tempted by premium audio op amps (Burr-Brown OPAx134), but they draw a lot of current. I decided to take a look at Texas Instruments CMOS op amps. These have good noise specs and low current consumption. The CMOS chips have "rail to rail" output drive (output peak voltage equal to power supply voltage), which affords a headroom advantage when running on low power supply voltages.

The TLC2202 dual op amp has excellent noise performance, plus high speed. It is a good choice for the first gain stage. However, it has some drawbacks -- it draws 1.1 mA per section, there is no quad package available, and it costs five bucks. I would need a pretty darn good reason to spend $25 on op amps.

It turns out that a compromise is possible. The TLC2264 is much less expensive, and has low noise, but is not a fast op amp. However, I realized that a bass won't ever put out a pure 20 kHz sine wave, and a bass speaker would not reproduce it anyway. A lower speed op amp is quite acceptable, because a bass signal will contain high frequency content, but only at low amplitudes. This combination of conditions makes slewing induced distortion – the bane of bad op amp circuit designs – unlikely. *Beware that this is a limiting assumption of the design, but not much of one. The chip has a rated maximum output amplitude of a couple Volts peak-to-peak at 20 kHz.* We will re-visit this issue in the section on perfromance measurements.

The power supply is somewhat elaborate, but is intended to be forgiving of input voltage variations. The TLE2426 "rail splitter" chip turns a single battery into a symmetrical split supply. A MOSFET switches power on and off through the "ring" terminal of the output jacks. Plugging a cable into either output jack turns on the power. I need this, because I am notorious for leaving things turned on and wasting batteries. Of course there's no law against adding a power switch to the circuit if you want, in series with the Psw signal, or by eliminating the MOSFET altogether.

The TLE2426 can handle higher power supply voltages, but the op amps cannot. The CMOS op amps are rated for a maximum of 16 V, so even a pair of 9-V batteries will result in certain death. To use a pair of batteries, add a 15-V regulator chip after the MOSFET. If you are running the preamp from a wall wart, either be careful to measure the DC output voltage (you might be surprised) or choose op amps with higher power supply ratings, such as the fabulous Burr-Brown OPA2134/4134.

Various parts of the design were modeled by Excel spreadsheets, calculations, or LTSpice. The download package contains LTSpice models of the EQ sections, so you can tinker with component changes.

How to deal with really hot pickups, active basses, and so forth? There does come a point where your input signal could clip the first gain stage. For sufficient headroom throughout the circuit, you probably want to stay below 2 V peak-to-peak at the input. If you are distorting the preamp at the lowest gain setting, consider changing R11 and R12 to 100k and 10k Ohms, respectively. This will give you a 20 dB cut at the front end. It is only applicable to magnetic pickups and active basses, but the problem is unlikely on piezo pickups.

Input clipping is one reason why some electric bassists prefer a preamp with a class-A front end, to provide some “soft” clipping and mild distortion. You could always add this. Once the signal is limited by the soft clipping function, then it can safely pass through the op amps unscathed. On the other hand, the BBBB preamp has a low enough noise floor to allow for padding the input without excessive degradation of signal-to-noise.

One use for the dual channel arrangement is to have one channel with the padded input for electric bass, and the other for upright bass.

Construction

The printed circuit pattern is designed using ExpressPCB. Don't trust the CAD file either, but check it yourself for correctness. This is always prudent when dealing with DIY designs. The board size to 3.8 x 2.5 inches qualifies for a special price on three boards from ExpressPCB, so don't change this size unless you have a good reason.

It is a mainstream through-hole design. All of the connections are to standard ribbon cable connectors. I have learned that these connectors are quite reliable, and that 28-gage rainbow ribbon cable is easy to work with. Why use connectors to the board? For DIY construction, it is helpful if the entire circuit board can be pulled out of the chassis for debugging and modification. I also start construction without the enclosure, and simply hook up all of my test cables to fanned-out ribbon cables.

Obviously, there is a lot of wiring in this preamp. It is possible to simplify things by eliminating the phase and mute switches. Having a pair of phase switches, rather than a single switch for relative phase between the channels, is a peculiarity of upright bass amplification -- intended to help control feedback. You might be able to simply jumper these connections for your specific setup. The same goes for the mute switch if you don't need it. But I don't advise changing the circuit board pattern just to remove features, because it doesn't save any money, and you might want the features later.

A commercial design would probably have all of the audio jacks on the printed circuit board. I consider this to be a bad idea for DIY gear, and perhaps also for commercial gear. It is too demanding of mechanical tolerances on the enclosure, and stress on jacks causes solder joints to break loose. Panel-mounted jacks may seem less "professional" in this day and age, but are a lot easier to work with using home shop tools. The build picture shows my preference for old-style Switchcraft jacks. Nobody has come out with a more rugged connector design.

Pin	Color	Input	Switches	Power / Output
1	Brn	Ch1	Mute	Batt +
2	Red	Gnd	Mute	Batt -
3	Org	Gnd	Sw2b	V-
4	Yel	Gnd	Sw2c	Psw
5	Grn	Gnd	Sw2c	V+
6	Blu	Gnd	Sw2a	Gnd
7	Vio	Gnd	Sw1a	Main Out
8	Gry	Gnd	Sw1c	Bal -
9	Wht	Ch2	Sw1c	Bal +
10	Blk	Gnd	Sw1b	Unbal

General Troubleshooting Advice

I can't tell you what to do if you build this circuit and it doesn't work, because it's going to be different in every case. The way to troubleshoot is by starting at one end and working your way to the other. I will share a general method that I follow for bringing a new circuit to life.

1. The best way of troubleshooting is not to build the entire circuit at once. Start with just the power supply section. You should see ±4.5 V at the IC power terminals when you ground the PSW terminal. Next, build up just one of the preamp gain stages, and so forth. Use an audio source of any sort, and the signal tracer as described below.

2. My test bench includes a digital voltmeter, student grade oscilloscope, various test cables and clips, soldering iron, de-soldering pump, and an old notebook computer running my audio diagnostic programs. Of these tools, you can do without the scope, though it's useful for diagnosing problems such as high frequency oscillation. Without the scope, you just have to be more resourceful with the other tools.

3. If you are really poor, create an old fashioned "signal tracer" by attaching a test probe to the input of a powered computer speaker, or a bass amp for that matter. The advantage of the computer speaker is that you won't go deaf if you misjudge the signal levels. Use the headphone output of a radio as the signal source. You'd be surprised to find that this works fairly well.

4. When I am starting out with a circuit, I don't bother with an enclosure. It gets in the way. Instead, I lay the circuit board out on my workbench and test it in the open. One reason is that it makes no sense to waste an enclosure if the circuit turns out to be crap.

5. In the case of the BBBB circuit, I started with just the components necessary to test the first gain stage, then proceeded to build up the circuit as I gained confidence. Again, this avoids wasting parts, and keeps things simple during troubleshooting. It is also a good discipline, because it forces you to work through the entire signal path with the scope or signal analyzer.

6. Re-check the power supplies every time you add more parts to the board.

7. Just a hint, based on diagnosing a bad pot in the tone controls when I first built the BBBB. With the tone control capacitors removed, the tone circuit is just a flat gain stage. You can test whether the treble control produces believable gain by shorting across the treble capacitor.

8. For tone shaping circuits, I always put the capacitors in little sockets scavenged from a "machine pin" IC socket. This lets me try different values based on a listening / playing test.

9. Before getting mad, or especially after, walk away and sit down somewhere quiet with the schematic and a beer.

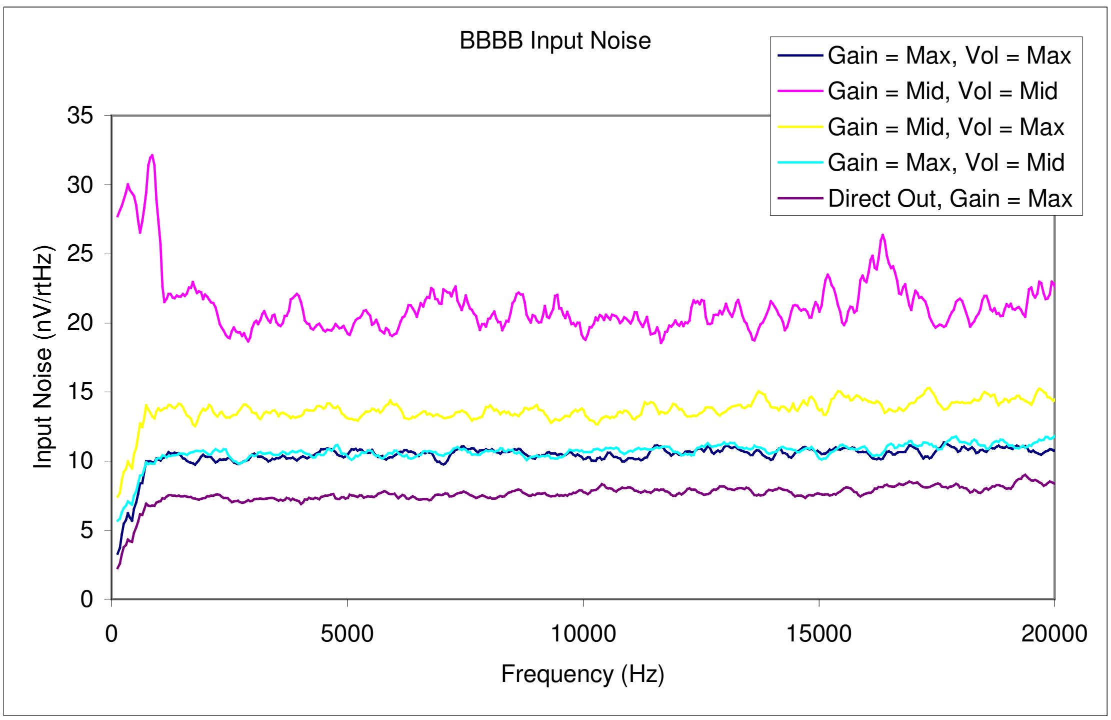
Performance Testing

How does the preamp stack up in performance tests? I have a reasonably complete suite of tests that I can run using the sound card on my PC as a signal generator and analyzer. It may be possible for me to share those tools at a later date, but not right now, because I have too much on my plate.

Noise -- Performing a good noise measurement is difficult in the home shop. I measure noise using a 100 kΩ resistor as a noise "standard," since it should produce 40 nV/√Hz noise at room temperature. I take a FFT spectrum with this resistor, and with the input shorted. The input noise at any given frequency is:

$$e_n = 40nV/\sqrt{Hz}\,\frac{v(0\Omega)}{\sqrt{v(100k\Omega)^2 - v(0\Omega)^2}}$$

This measurement has the advantage of not having to know the absolute voltage scale for the FFT analyzer, which is an unknown when using a PC audio input. My measurement conditions are: One channel is unplugged and turned all the way down. The other knobs are centered unless otherwise noted. The noise curves are shown here:



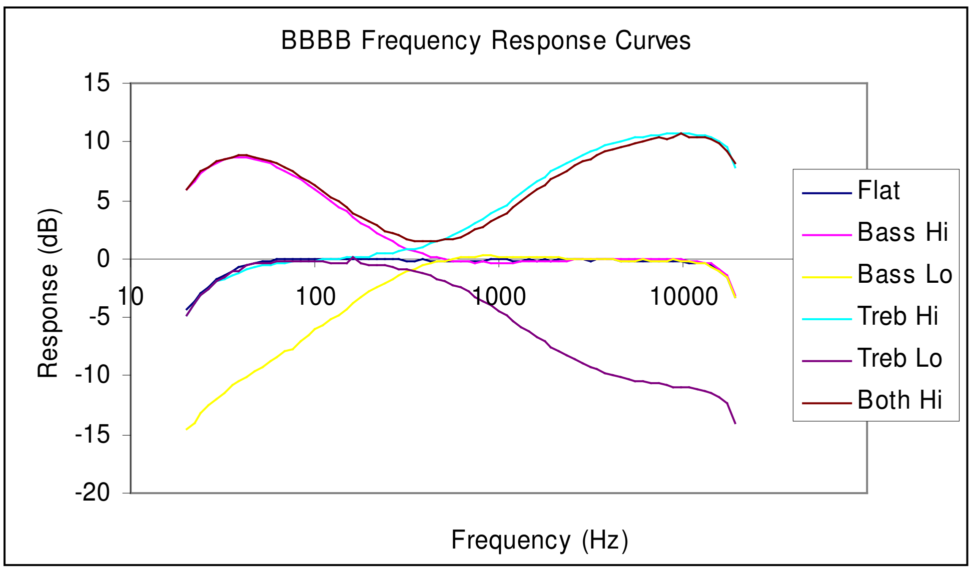
With both gains at maximum, we are seeing the raw input voltage noise of the TLC2202 op amp, along with contributions from R11 and R14. The TLC2202 is rated at 8 nV/√Hz, so we are definitely in the ballpark of ideal performance with this circuit. Lowering the input gain raises the noise a bit, as the higher resistance from the potentiometer begins to affect the noise picture at the front end. Likewise, lowering the master volume makes things worse because the final stage begins to contribute a larger proportion of the total noise. The graphs do show that dynamic range can depend on the relative settings of the input and output gains, but the variation is within a few dB.

For reference, premium JFET op amps can achieve 6 nV/√Hz, discrete JFETs (2N4393) can get down to 2 nV/√Hz or even lower. The 12AX7 triode tube is rated at roughly 18 nV/√Hz (typical hum and noise), but could theoretically be pushed into the 12 nV/√Hz range. I think the 12AX7 is the quietest tube out there.

Some bipolar op amps have very low input voltage noise, but they are not suitable for high impedance sources, and will experience large DC offsets in the BBBB circuit. Avoid bipolars altogether unless you are willing to modify my design to balance the input bias currents.

Signal-to-Noise -- I consider this to be a secondary spec, but it is interesting if you want to make a comparison to commercial preamps. I have computed the RMS input noise of the preamp from the noise curve. An input noise voltage of 10 nV/√Hz works out to -117 dBV over a 20 kHz bandwidth. This is unweighted. Theoretically, an "A" weighted measurement would be a few dB lower, but I did not compute one. Thus, a -10 dBV input signal would enjoy a respectable 107 dB signal-to-noise ratio. This exceeds the signal-to-noise of most power amps, which are typically in the ballpark of 100 dB at clipping. We are achieving excellent noise performance, though a studio quality preamp could achieve another 10 dB at some expense in high-level signal handling.

Frequency Response -- I am using a traditional swept-tone technique, rather than a FFT, simply because it appears to produce cleaner graphs. The response curve is shown for different tone control settings:



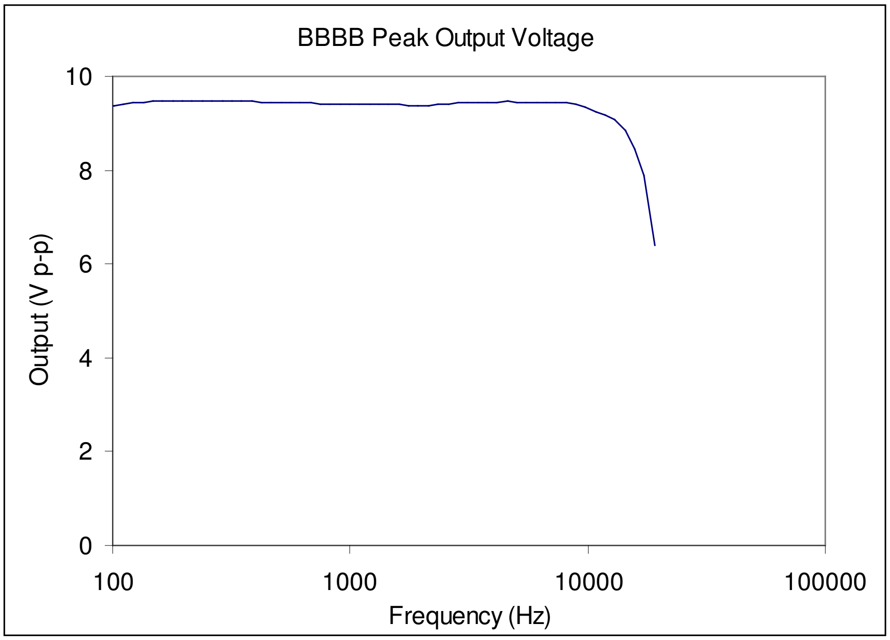
For the tone controls centered, the response is down by about 1 dB at 40 Hz, the lowest note of a 4-string bass. This could be easily extended by increasing electrolytic capacitor values in the front end stage. Remember that cutoff frequencies in Hertz are equal to 1/pi/R/C, with R in Ohms and C in Farads. The curve with both controls turned up shows that there is reasonable independence between the controls. All of this simply owes to the cleverness of this classic tone circuit, invented by Baxandall, and preceded with a passive version by James, in the 1950's. The "hook" near 20 kHz is an artifact of the anti-aliasing filter in my PC sound card.

Power Response -- This is a graph of maximum peak output voltage versus frequency, for driving a 10-kΩ load from the main output. The purpose of this graph is to address my own concerns about the headroom of the preamp at high frequencies when using relatively slow CMOS op amps. Where the output amplitude is flat at 9.4 Volts peak-to-peak, the preamp is delivering a sinewave barely below clipping. This is almost equal to the battery voltage, thus confirming "rail to rail" operation of the op amp.

At frequencies where the amplitude begins to fall, the preamp is running at the slew rate limit. This is equivalent to a frequency dependent clipping threshold below the DC clipping level. It is not a frequency response curve for small signals.

My interpretation is that the preamp is absolutely uncompromised by the slew rate limit, when reproducing any realistic music signal. Though a music signal contains high frequency content, the amplitude is small.

Thus, a music signal will not encounter slew limiting. And even with high frequency test signals, the power response limit is probably above the level required to drive a typical power amp into clipping.



Mods and Substitutions

Padding "hot" piezo pickups – the correct way is with a capacitor in parallel with the input. This is counterintuitive, but it preserves the frequency response of your pickup, because the pickup acts as a voltage source in series with a capacitance. Thus, the padding capacitor turns the circuit into a purely capacitive voltage divider with flat response. Try a 0.01 µF film capacitor. Adjust the exact value to taste. Every audio hobbyist should have a collection of different values of polymer film caps.

Padding electric bass pickups – active or passive, just use a resistive divider with 100k and 30k resistors for –10 dB padding, or 100k and 10k for –20 dB. Custom-padding each input for a particular instrument is a perfectly good use for a dual-input preamp.

Changing op amps – this can be an amusing but relatively harmless experiment. The BBBB will work with practically any FET-input op amp, if it can handle a 9-Volt power supply. The absolute premium audio op amps are the OPA134 series (OPA2134 and OPA4134 are the dual and quad versions). These will also handle much higher supply voltages than the CMOS op amps that I am using.

Power options – the op amps that I am using are rated at an absolute maximum of 16 V. Thus, running on 18 V requires changing op amps. You won't double your headroom, and battery life will plummet. You could run on 15 V by passing the 18-V supply through a 78L15 regulator chip. All of this seems to me like more trouble than it's worth. If you want to run the circuit on external split supplies then you must remove the TLE2426 chip. This would be a case where the OPA2134 and OPA4134 chips become a viable option.

Wall warts – while a good option for powering the BBBB, beware that the DC output rating does not tell you the actual output voltage under all load conditions. Most wall warts will put out a higher-than-rated voltage at the current level being drawn by the BBBB circuit. *Measure the voltage before subjecting the TLC op amp chips to greater than 16 V.* If you don't know what to buy, your best bet is probably a 9 VDC wart. The typical 12-Volt wart is quite likely to exceed 16 V. Measure it. Another thing is, you can always put in the 15-V regulator chip.

Power jacks – note that neither terminal of the battery is grounded. If you want to have a power jack, it has to be isolated from the metal case of your preamp. There are all-plastic power jacks that you can use.

Freebie: Parametric EQ

I designed this Parametric EQ circuit, and you will notice that it's laid out on the printed circuit pattern as shown above. Watch this space for more information.