A Flexible Subwoofer Amplifier, Part 4

Adjustments, Testing, and New Ideas.

By Rudy Godmaire

PHOTO 1: The subwoofer amp.

Parts 1-3 explained the design and the making of my subwoofer amp. In this last part, I will discuss its performance and share some measurements, tuning procedures, and listening impressions. As a "bonus feature" (see sidebar), I will give some hints on how to make two very nice preamps using the same PCBs.

OVERVIEW OF THE PERFORMANCE

Figure 1 summarizes the behavior of the subwoofer amp with a dummy load of 5Ω. Using a test disk (*Stereophile* Test CD 3, track 17) and an input signal of 0.5V RMS in each stereo input of the subwoofer amp, I generated various frequencies and measured the output voltages at the binding posts. The results are shown for two cutoff frequencies f_{cLP}: 48Hz and 80Hz.

It is interesting to compare the simplified theoretical slopes of attenuation represented by the thin dotted lines, and the real ones depicted with the bold lines. Though the real attenuation slopes begin to drop sooner than I expected, they nevertheless cross the −18dB point at almost the same place as the theoretical slopes. This graph clearly shows that the third-order low-pass Butterworth active filter does its job as intended.

These results with a dummy load are very satisfying. However, what interests me is the behavior in real-world situations. **Figure 2** presents the low-frequency response of my sound system with my subwoofer amp fine-tuned for music reproduction (f_{cLP} = 48Hz). I made all measurements with an SPL meter (Tenmars TM-102) from my listening position, at a moderate sound level. I used C-weighting measurements to perform all adjustments because this type of frequency weighting provides accurate results on the true SPL produced by the equipment.

Looking at this figure, you can see that the subwoofer improves the frequency response between 60Hz and 40Hz. At 60Hz, the main loudspeaker curve (thin curve) begins to drop, while it remains rather flat when the subwoofer is on (bold curve). Below 40Hz, the contribution of the subwoofer drops sharply due to the limitations of my passive subwoofer. Better extension of the frequency response to the lowest octaves will need to come from a better passive subwoofer.

This graph also reveals weaknesses in my room acoustics. You can clearly observe two dips at 80Hz and 125Hz and also a peak at 40Hz. These irregularities have to do with the dimensions of

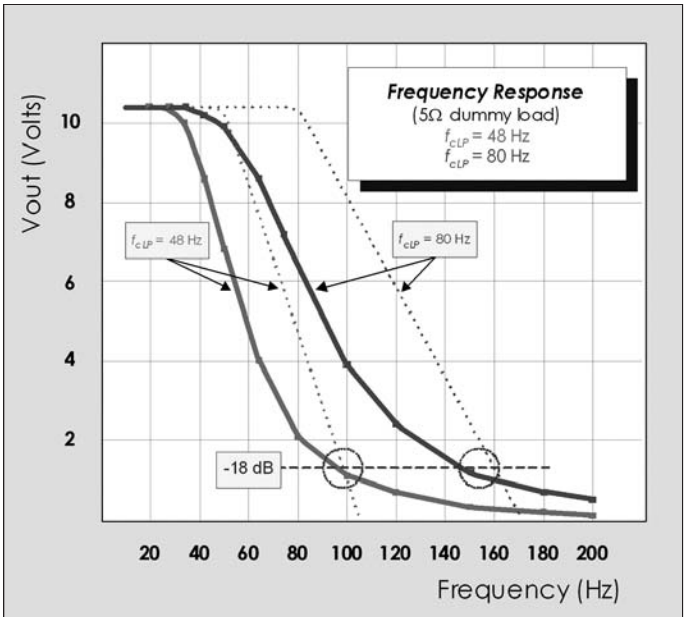

FIGURE 1: Frequency of the subwoofer amp as a function of f_{cLP}.

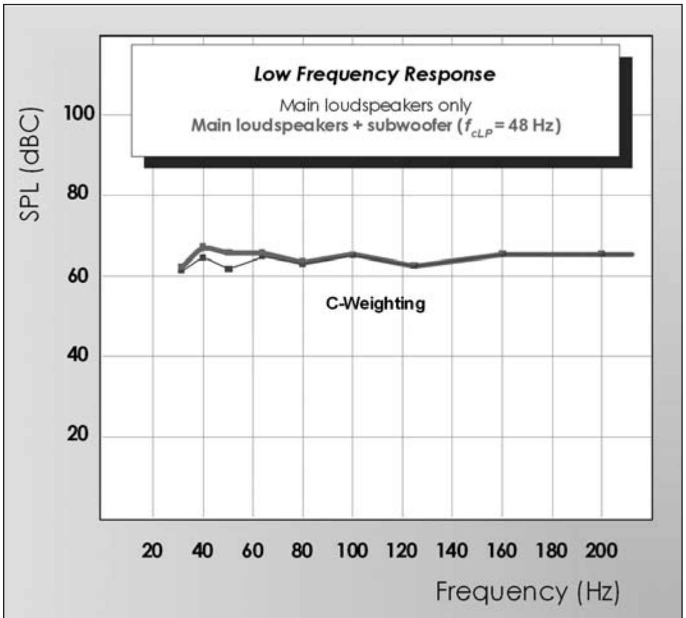

FIGURE 2: Low-frequency response of the sound system with f_{cLP} = 48Hz.

my listening room. These room modes might be smoothed out with the use of additional wall treatments. Without any doubt, this experiment confirms that the listening room is an important building block of the sound system.

FINE-TUNING THE SUBWOOFER AMP

Integrating a subwoofer to a sound system always offers some challenges to the audiophile. Thanks to the features of the subwoofer amp, it is possible to achieve excellent results. Three parameters need to be optimized in order to provide the best performance: the sound level, the cutoff frequency f_{cLP}, and the phase shift.

Adjusting the phase shift is probably the most difficult step of the setup procedure. A good understanding of the behavior of the phase shift is very helpful in making the right decisions. For that reason, I provide some more theory about the phase shift before adjusting the subwoofer amp.

PHASE SHIFT THEORY

In Part 1, I stated that changing the frequency of the musical signal *f* would change the phase as well. The consequence of this is that the phase can only be optimized for one specific frequency. How will this impact my system? To answer this question, I computed many different values using equation 4 of Part 1. The results are compiled in **Table 1**. An example will show how to use this theoretical data.

Suppose for a moment there is no low-pass filter preceding the all-pass filter stage, so that the musical signal f is not attenuated at any frequency. First play a sine wave test tone of 50Hz simultaneously through the main loudspeakers and the subwoofer. The objective is to get the loudest and cleanest bass possible, indicating that the sound waves of the main loudspeakers and the subwoofer are in phase. Using a SPL meter, set the best position for the phase inverter switch S_3 and then begin to adjust the phase shifter potentiometer P_1/P_2. After some trial and error, you'll find an optimum adjustment.

Taking a DMM, measure P_1 (or P_2) at, say, 17,750Ω. This determines the cutoff frequency of the all-pass filter (f_{cAP} = 70Hz). Looking at **Table 1**, you find that the phase shift at 50Hz is –142°. Now, suppose you play a signal of 30Hz. The phase shift will be –92°, a change of 50°. Should you play a signal of 100Hz, the phase shift will be –220°, a change of –78° with regard to 50Hz.

Are these deviations objectionable? Maybe not, in my opinion. You must remember that the previous stage will be, in fact, a third-order Butterworth low-pass active filter. Its attenuation slope of

P_1/P_2	50 000	47 750	35 000	27 000	21 500	17 750	15 000	12 750	10 900	8 300	4 950	0
f \ f_{cAP}	29 Hz	20 Hz	40 Hz	50 Hz	60 Hz	70 Hz	80 Hz	90 Hz	100 Hz	120 Hz	160 Hz	318 Hz
30 Hz	-184	-180	-148	-124	-106	-92	-82	-74	-66	-56	-42	-22
40 Hz	-216	-212	-180	-156	-134	-120	-106	-96	-88	-74	-56	-28
50 Hz	-240	-236	-206	-180	-160	-142	-128	-116	-106	-90	-70	-36
60 Hz	-258	-254	-226	-202	-180	-162	-148	-136	-124	-106	-82	-42
70 Hz	-270	-266	-242	-218	-198	-180	-166	-152	-140	-122	-94	-50
80 Hz	-280	-278	-254	-232	-212	-196	-180	-166	-154	-136	-106	-56
100 Hz	-296	-292	-274	-254	-236	-220	-206	-192	-180	-160	-128	-70
120 Hz	-306	-304	-286	-270	-254	-240	-226	-212	-200	-180	-148	-82
160 Hz	-318	-318	-304	-290	-278	-266	-254	-242	-232	-212	-180	-106
200 Hz	-328	-326	-314	-304	-294	-282	-274	-264	-254	-236	-206	-128
320 Hz	-340	-338	-332	-324	-318	-310	-304	-298	-290	-278	-254	-180
400 Hz	-344	-342	-338	-332	-326	-320	-314	-310	-304	-294	-272	-206

TABLE 1: Phase shifting (in degrees) as a function of the cutoff frequency f_{cAP} and the frequency of the musical signal f.

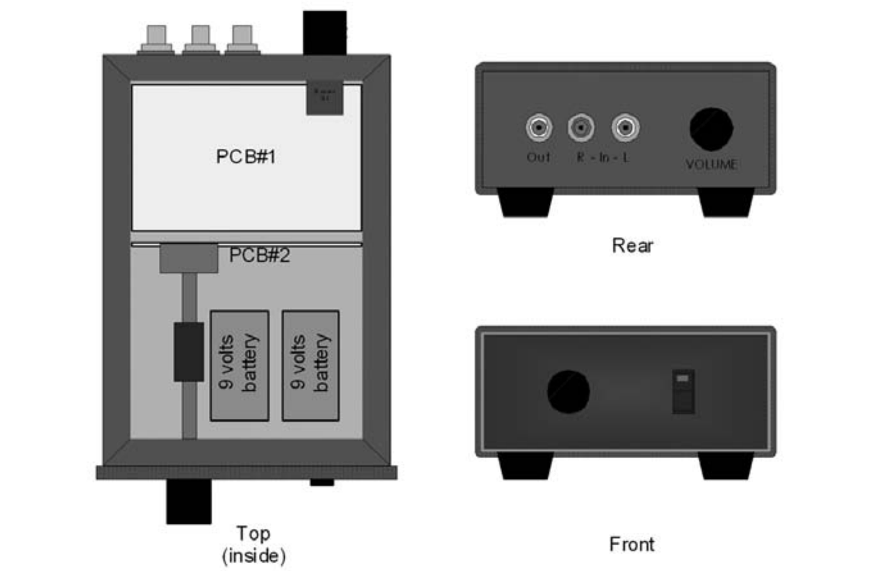

FIGURE 4: Sketches of the battery-powered subwoofer preamp.

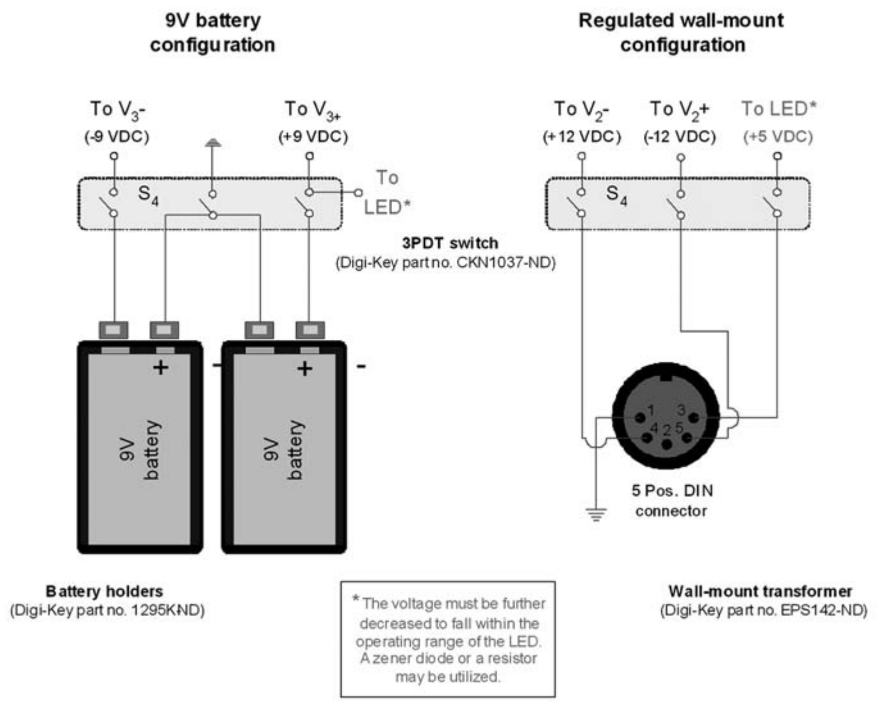

FIGURE 5: Suggested connection of S_4 for the subwoofer preamps.

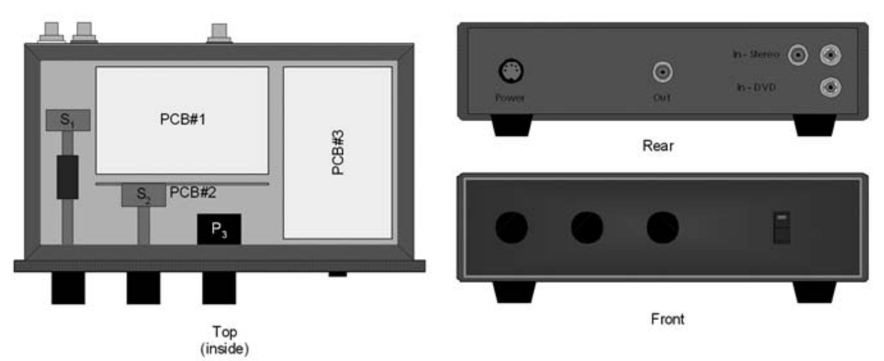

FIGURE 6: Sketches of the full-featured subwoofer preamp.

HOW TO MAKE TWO SUBWOOFER PREAMPS

Suppose you are interested in the features offered by the preamplifier stage but do not need the amplifier section. What could you do? Adapting the design to make a separate preamp is very easy. Using the same PCBs, I will explain how to build two superb subwoofer preamps.

BATTERY-POWERED SUBWOOFER PREAMP

Imagine you want a simple design. Why not merely replace the power-supply stages—unregulated and regulated—with 9V batteries? Then all you need to do is assemble PCB #1 and 2; add three RCA connectors (one pair of stereo inputs, one output), P_3, S_4, a LED, and that's it!

Figure 4 gives you an idea of how you could position the components. Note that I have placed the volume control at the rear of the chassis. This configuration minimizes the wire length and also keeps the unit as small as possible. In this example, a 5″ × 7″ × 2″ Hammond chassis would fit nicely.

You could upgrade this preamplifier by replacing the 9V batteries with a regulated wall-mount transformer. Models such as the WM063 from Elpac Power Systems provide ±12V DC and 5V DC connections with an output ripple of 20mVp-p. The ±12V DC should feed PCB #3 to further improve filtering, while you could utilize the 5V DC to power the LED.

The proposed layout offers sufficient room to accommodate the placement of PCB #3 in lieu of the 9V batteries. **Figure 5** also suggests a flexible approach that will ease the upgrade of a battery configuration to a regulated wall-mount configuration, with the simple addition of a 3PDT switch.

FULL-FEATURED SUBWOOFER PREAMP

You may prefer a preamp that would somehow replicate the design of the subwoofer amp without its amplifier module. To keep the preamp small, I recommend the use of a wall-mount transformer for this project. **Figure 6** suggests that you could build such equipment using a 5″ ×

–18dB per octave will greatly attenuate the effects of these unwanted deviations as the frequency of the signal increases.

The key here is that the cutoff frequency f_{cLP} of the third-order Butterworth low-pass filter should be in the vicinity of the cutoff frequency of the main loudspeakers. The lower the crossover point, the better. On the other side of that cutoff frequency, a good subwoofer will take over the main loudspeakers down to the lowest octaves. So whether there is a deviation at these frequencies should not seriously impact the end result.

All this is a simplification of the reality, however. To be truly accurate, you would need to consider the phase shifts introduced by all other filters in the circuit, and mainly by the third-order Butterworth low-pass active filter. It is important to understand that the phase shift will be optimized not only for one frequency f but also for one specific cutoff frequency f_{cLP}.

On the basis of that knowledge, I chose to adjust the phase shift to get the highest fidelity possible when listening to music, and aligned the phases while using the cutoff frequency f_{cLP} dedicated for music listening. You may wish to set a different alignment. In any case, **Table 1** will help you predict the behavior of your setup.

ADJUSTING THE VOLUME LEVEL

I connected the stereo outputs of my preamp to both my dual mono tube amps and my subwoofer amp. This configuration allows me to control the sound level of the entire system with my preamplifier.

As Fletcher and Munson demonstrated a few decades ago, our ears do not perceive all frequencies with the same ability. So it is important to make sure that you perform all your adjustments on the right basis. I suggest that you first listen to music at the volume level you are used to. Then using an SPL meter, try to figure out the average SPL of the musical content. This will be your starting point. In my case, I averaged an SPL of about 65dBC.

From there, you need to set the volume of the main loudspeakers and the subwoofer, separately, to this level. Using a test disk (*Stereophile* Test CD 3, track 17), I played a test tone of 60Hz and adjusted the volume levels to get about 65dBC. The value of 60Hz is arbitrary.

What is important is that you must use a frequency higher than the cutoff frequency of your main loudspeakers (40Hz in my case) but lower than the cutoff frequency of the subwoofer amp. I used the cutoff frequency f_{cLP} of 100Hz to make sure the 60Hz signal was not attenuated when I adjusted the volume control. If you need to use a higher frequency to perform this procedure, I suggest you prepare a small chip of resistors that will provide you with a higher cutoff frequency.

CUTOFF FREQUENCY AND PHASE SHIFT SELECTIONS

Your objective now is to find the optimum cutoff frequency f_{cLP} and phase alignment for the subwoofer amp. Ideally, the sub-

9″ × 2″ Hammond chassis.

You could also try a 15 VA toroidal transformer providing dual secondary windings of 12V AC. In this case, PCB #4 rectifies the AC voltages and provides approximately ±16V DC, just perfect to power PCB #3. You would need to modify some components (referring to Fig. 10 of Part 1).

Replace the 4700µF/80V capacitors with four 2200µF/25V capacitors, skip ZD_1 to ZD_5, and replace them with jumper wires. Replace ZD_6 with a 14V/5W zener diode. D_1 to D_4 would remain the same, or, you could replace them with a lower voltage type. As for R_{26}/R_{27}, you could simply replace these resistors with jumper wires because the inrush current will be limited. The only downside of this configuration is that you would need a larger chassis to receive PCB #4 and the power transformer.

Whether it is a battery-powered or a full-featured subwoofer preamp you intend to build, I recommend you use only shielded interconnect cables between the preamp and all other components. The design seems to be vulnerable to RFI, and you should do everything to minimize that susceptibility. Aside from this, I am truly confident that either preamp works just fine. ■

woofer and the main loudspeakers should blend in a seamless manner while extending and flattening the frequency response to the lowest octaves.

Experimentation was very easy through the use of five chips of resistors that provided me with the following cutoff frequencies: 35Hz, 39Hz, 44Hz, 48Hz, and 52Hz. Within seconds, it was possible to swap one chip for another.

I made the first set of measurements with my main loudspeakers alone. I played test track 17, from 200Hz down to 31.5Hz (the lower limit of my SPL meter), and computed the SPL values in a spreadsheet from which I produced the thin curve in **Fig. 2**. The frequency response then appeared quite bumpy, revealing room acoustic problems as mentioned before.

I carried out the following procedure for each chip of resistors:

1. Using a test tone of 40Hz, the cutoff frequency of my main loudspeakers, I played that signal simultaneously through the main loudspeakers and the subwoofer.

2. I first switched the phase inverter S_3 in the position providing the loudest bass. (Note: Once you do this, you do not need to modify this setup for the subsequent chips.)

3. Then I made various attempts to adjust P_1/P_2 and found an optimum adjustment after a while. SPL measurements indicated that the bass was at its loudest (67dBC).

4. I turned down the volume of my subwoofer amp to get an overall level of 65dBC.

5. Finally, I played test track 17 and computed the values in my spreadsheet. You might need to redo this step a few times because the volume level might require further correction to get the flattest response possible.

After completing the procedure for all five chips, I compared the data and concluded that the 48Hz cutoff frequency was the optimum choice for music listening.

FINAL THOUGHTS

After completely fine-tuning my subwoofer, I decided to make some final SPL measurements, but this time with my preferred cutoff frequency for home theater (f_{cLP} = 80Hz). The data computed in **Fig. 3** led to some very interesting observations. The subwoofer emphasizes the frequencies from 125Hz down to 50Hz. The third-order Butterworth low-pass active filter does a pretty good job, because the

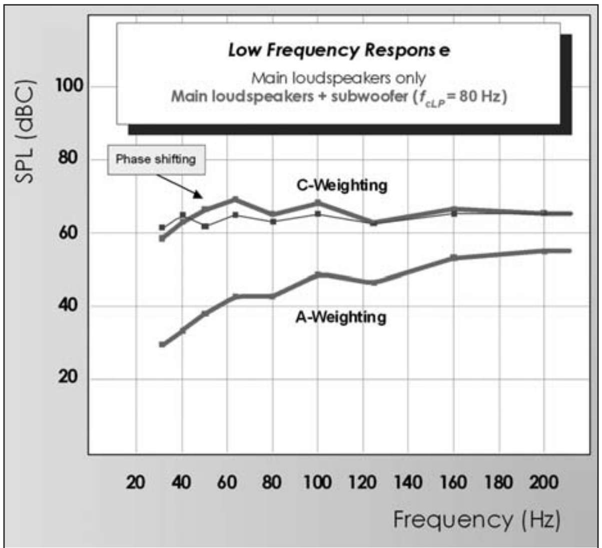

FIGURE 3: Low-frequency response of the sound system with f_{cLP} = 80Hz.

influence of the subwoofer disappears over 125Hz. However, below 50Hz, you can see that a phase shift occurs as the SPL becomes lower with the subwoofer compared to the main loudspeakers alone!

This experiment clearly demonstrates that the phase alignment can only be optimized for one specific cutoff frequency. Maintaining perfect alignment for each of the three cutoff frequencies would require you adjust P_1/P_2 every time. Because I had no intention of fiddling with this potentiometer, I positioned it inside the amp, directly on PCB #1. Music being my priority, I can easily live with this deviation when I listen to a movie. Should your preference be different, you will need to experiment further to determine a different compromise.

Out of curiosity, I also measured the SPL using the A-weighting that is meant to correlate to the behavior of the human ear. My physiological perception was somewhere between the C-weighting and the A-weighting, but the tendency confirmed the works of Fletcher and Munson. Looking at this curve in **Fig. 3**, you could argue that our ears are not electronic instruments and that subjectivity should be allowed when setting the volume level. To a certain extent this is right.

If you tuned your system on the basis of a moderate SPL (65dBC in my case), you may wish to readjust the volume level of the subwoofer amp a little higher so that you have a better physiological perception of the lower spectrum. You must be careful, however, not to exaggerate. You should never feel the presence of the subwoofer in the room. You should extend the low-frequency content to the lowest octaves and thus bring some support to the main speakers. Also, instruments should sound in your listening room as close as possible to the way they would sound in a concert hall. Having said that, music is a matter of preference and I am sure you will tune it to your taste!

One last word about tuning. I have not talked about subwoofer placement. This is another important aspect I intentionally omitted because in my room my passive subwoofer can be positioned in only one place. If your room offers you the flexibility of moving your passive subwoofer around, then I encourage you to experiment with its placement.

LISTENING IMPRESSIONS

It is well known—and I can confirm this—that the use of a subwoofer adds to the movie experience. Aside from the spectacular sensations provided by the low-frequency effects, I found that the clear winner is ambiance, which offers me the greatest satisfaction. The feeling is subtle but very important; it really gets you into the movie.

What is true for movies is also true for music. Adding a passive subwoofer controlled by a full-featured subwoofer amp contributed to my listening experience. Instruments such as piano, organ, and double bass are more involving and emotional. For example, when the pianist hits a low bass note on a grand piano, I feel more intensely—almost physically—the full weight of that note. The play is more realistic, closer to the real thing. And because the cutoff frequency is very low, I never perceive any adverse effect of phase deviations between the subwoofer and the main loudspeakers.

Again, the adjustment of the volume level is highly important. Whether you listen to a movie or to music, you should never hear the subwoofer itself.

CONCLUSION

I hope you have enjoyed the description of my journey involving the design and construction of my subwoofer amp. And, more important, I hope it has inspired you in your own projects.

Should you attempt to build this subwoofer amp or one of the preamps, I will be glad to offer you some support. Readers can communicate with me at my e-mail address r.godmaire@sympatico.ca. I will do my very best to answer e-mails in a timely manner. Enjoy the hobby! *aX*

Note: We are pleased to announce that the four PCBs (on a single board) are now available through *audioXpress* as a kit for $60.

A word from the author: Since the submission of my article, I have performed several improvements to my boards which you will see in this kit.—R.G.