Simple Servo Sub 100/120 Modification

Try these simple fixes to "go low" with Parts Express' subwoofers.

By Bill Waslo

This quick-gratification loudspeaker project involves little or no carpentry, moderately low expense, and perhaps a weekend of effort once you gather materials and tools. And when you're done you'll have a compact, high performance, powered servo subwoofer with a solid very low-frequency response and nicely detailed sound.

I started on this after I obtained a pair of Bohlender Graebener (BG) Radia 520i floor-standing planar magnetic hybrid loudspeakers. These each use a 50″ dipole ribbon line source covering high treble down to about 350Hz, and a pair of 6.5″ cone drivers in a sealed enclosure to go down to about 80Hz. The difficult transition between dipole and sealed box is handled well by the design of these loudspeakers, and the midrange in particular is outstanding.

But these speakers absolutely need subwoofers. The exceptional midrange and treble only highlighted to me that bass is mostly missing below 80Hz. I use my system, by the way, mostly for listening to music. I'm not really after high fidelity reproduction of the sound of explosions or dinosaur footfalls.

I'm not a particularly avid carpenter. I don't have a full wood shop and am becoming more sawdust-averse as I age. I knew I wouldn't have the time or motivation to do a full from-scratch subwoofer project anytime soon. In need of a temporary work-around, I started looking to see how much a minimally capable subwoofer would set me back.

PHOTO 1: Sub120 enclosure, with grille.

On the www.diyAudio.com forum, I ran across several mentions of Dayton Audio's inexpensive powered subwoofers that were said to be about the best you could buy without digging deeply into your bank account. The Sub100 model happened to be on sale from Parts Express (www.partsexpress.com) at the time, so I ordered one.

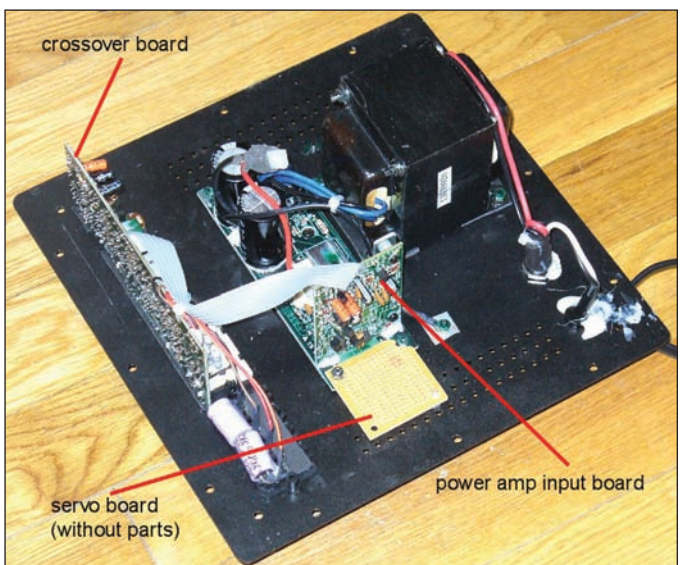


PHOTO 2: Inside the plate amp, with placement for the added servo board.

I was pleasantly surprised at what you could get for a little over 100 bucks. This ported design uses a 10″ driver in a nearly cubic box roughly 16″ on each side (the Sub120 uses a 12″ driver in a slightly larger box). The subs seem to be decently made and have good cosmetics (**Photo 1**), particularly considering the price. An active 4th order Linkwitz low-pass crossover is built onto the "plate amplifier" chassis and provides an adjustable crossover point, level control, and polarity switch.

The power amplifier portion of the plate amplifier can give about 100 to 150W depending on load impedance and uses an appropriately large power transformer (**Photo 2**), though rather small filter capacitors. I measured the near-field response of the sub and found it to have an f_{-3} point in the high 40s. In typical use the room "lift" pushes this effectively lower, and the sound from the unmodified sub really isn't bad at all.

But like most DIYers, I can't leave well enough alone, and wanted to get lower still. And I have some accelerometers. . .

MOTIONAL FEEDBACK

The basic idea of motional feedback is to actively measure the movement of a woofer cone and, using a feedback control loop, force the cone to move as necessary to produce sound matching the musical signal. The loop produces an error signal that works with processing circuitry to constantly correct the woofer movement. For a sealed box woofer that is much smaller than a wavelength, the radiated sound will be proportional to the cone's acceleration, so the feedback loop should be arranged to slave the cone's acceleration to the input drive signal. Acceleration can be measured using an accelerometer, of course. You will also need to add some circuitry to sum the feedback signal to the input and to tailor the magnitude and phase response within the feedback loop to keep the system stable.

While it would be possible to design a vented box motional feedback system, it would be much more complex (be-

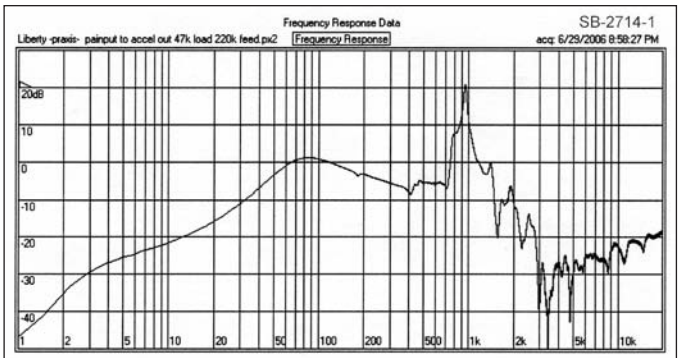


FIGURE 1: Initial feedback gain response of power amplifier, woofer, and accelerometer.

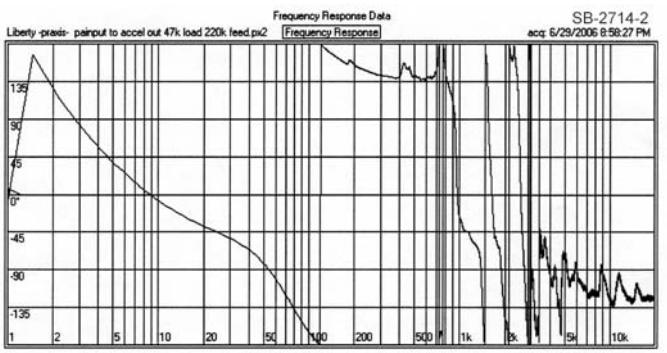


FIGURE 2: Phase response corresponding to *Fig. 1*.

cause the output doesn't all come from the cone) and could not be used to extend the frequency as low because the port and cone output cancel at very low frequencies. So for this project, you need to seal the port openings of the sub enclosure. I'll leave this part to your ingenuity.

You can use stoppers if you can find the right size. I found some glass stoppers from old kitchen storage containers that fit perfectly. Or, you can epoxy small rectangles of wood over the port openings on the outside of the box. You need to seal them very tight—just stuffing cloth or foam into the ports will not do.

A benefit of using motional feedback is that the system frequency response becomes much less dependent on driver or box parameters, in effect equalizing the response flat down to very low frequencies (or however the crossover's response dictates). Also, within the frequency range where the feedback is effective, distortion products are reduced.

But there are limitations to what feedback can do. It doesn't increase the size or range of movement of the driver, so while feedback may somewhat increase how far the driver can be pushed before distortion becomes really ugly, the acoustic output level is still limited by what the driver can do. Also, the frequency range over which you can use motional feedback will depend on the "raw" system response.

FEEDBACK LOOP

I don't intend to get into any extensive feedback theory here, but I will cover some basics. In particular, you need to

know what you don't want, which is an oscillator!

A feedback loop will oscillate when a signal at the output results in a feedback signal (back at the input) that causes the exact same signal to happen over again at the output. The signal becomes self-sustaining.

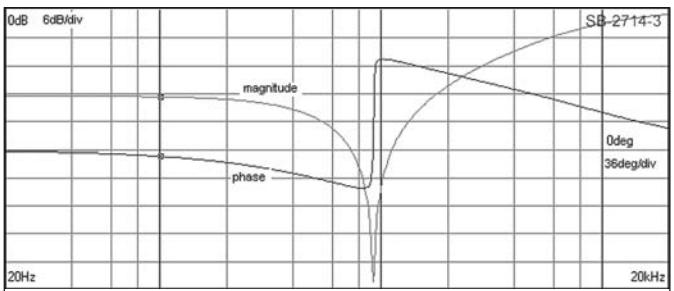


FIGURE 3: Modeled attenuation and phase of the notch/lead network.

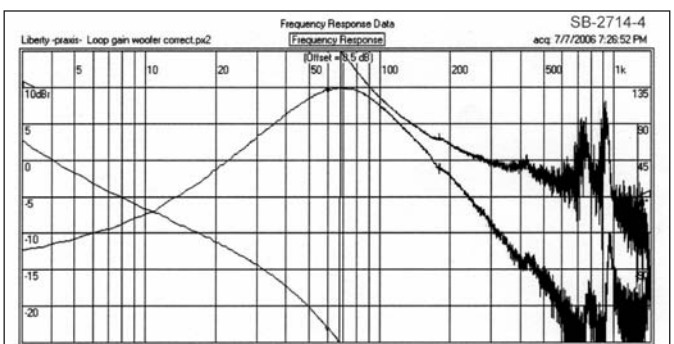


FIGURE 4: Loop response of servo system with leaky integrator and notch filter.

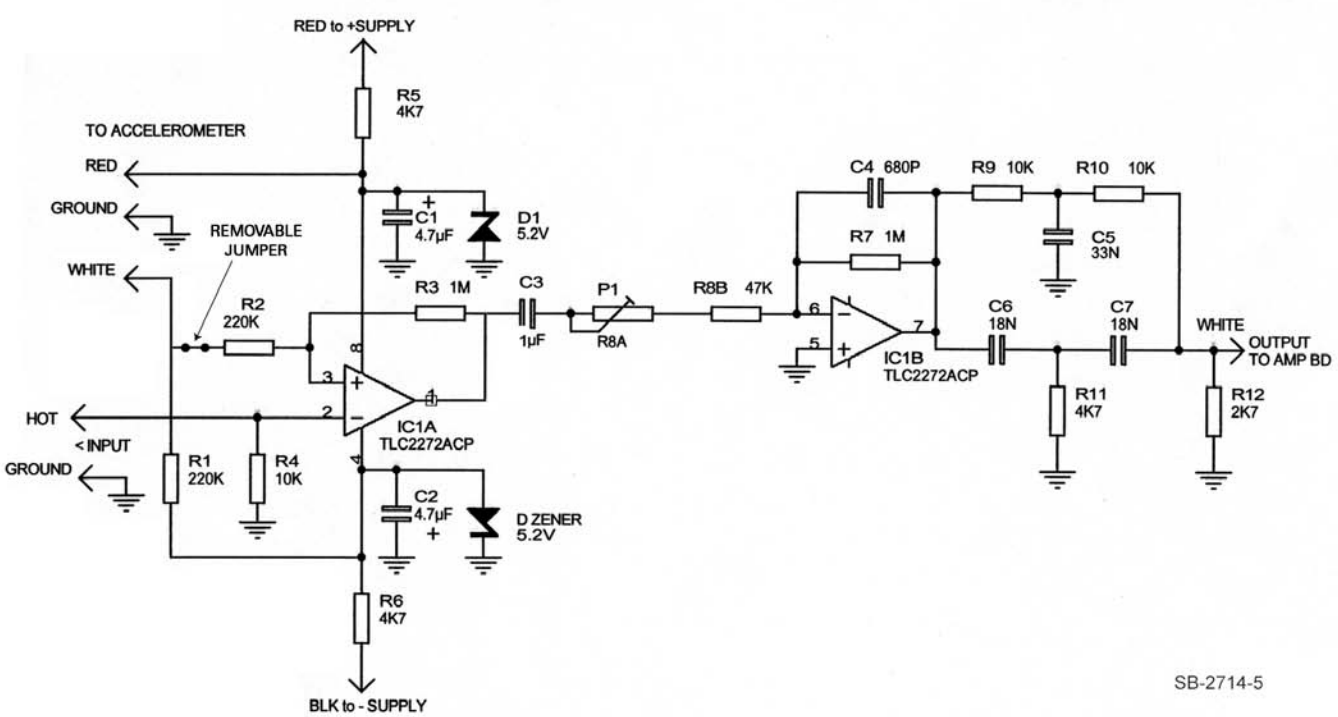
In terms of the "loop response," this means that oscillation will occur at the frequency where the feedback signal generated from the output—were it to be interrupted from getting back to the input—would have unity (i.e., 0dB) gain and no phase shift relative to a driving signal at the feedback injection point. If this loop gain is less than 0dB, then the system is stable. If the feedback never gets to 0° phase shift, you are OK, too. Both conditions must happen together for sustained oscillation.

It may seem as though it should be easy to ensure that loop phase never goes to zero at the exact same frequency where loop gain goes to 0°. But, of course, things are not so easy.

When the loop gain is above unity, and the phase is near 0, the system output does not oscillate right off, but instead increases in amplitude with time—imagine the feedback causing an even stronger output each time through the loop. And eventually as the output signal grows, the system (amplifier or speaker) will run out of dynamic range and the output will begin to compress or clip, which reduces the gain. And when the gain becomes reduced back to unity, then you get the sustained oscillation—and at full capable power! That is not a good situation for a subwoofer. You want the feedback to be negative, not positive, so that there is no output when there is no input.

So you need to make sure that at any frequency in the loop's response, the loop phase never goes through zero degrees

FIGURE 5: Schematic of servo board circuit.



when the loop gain is above 0dB. And because physical parameters can change, you want some margin to make sure things stay stable.

MEASUREMENTS

During design of a feedback system, it helps to be able to measure the system responses and model the loop response. This requires some measurement gear, however, and some insight into what needs to be measured. For this project, I've done that part already. However, if you want to start from scratch or use other components than those described in this article, you should get the appropriate equipment to measure gain and phase response of electrical networks.

Here's what you are up against with the Dayton Audio subs. **Figure 1** shows the measured gain response of the power amplifier, sealed-box woofer, and the accelerometer I used, relative to the input drive signal. (The figures in this article are taken from a modification done on a Sub120, but the Sub100 is very similar, and the identical modifications described here also work with it.) The main frequency range of interest for a subwoofer is below 100Hz, but look at the big resonant spike at about 900Hz! As **Fig. 2** shows, the phase is going all over (including through the forbidden 0°) near the same frequency.

You want high loop gain, with near 180° phase shift, in the frequency range where the sub will play. But the highest gain on the initial response is at this 900Hz resonant spike—and the phase changes really fast through it, as will happen with sharp resonances. The feedback system is sure to oscillate near there unless you do something about it. The resonance probably happens because of the cone flexing where it breaks up and stops acting as a piston, and adding even the small mass of the accelerometer to the dust cap does not help matters.

SOLUTIONS

So, what can you do? One manufacturer embeds the accelerometer within the voice coil assembly itself, along with carefully placed counterweights, to minimize coupling of the cone resonance to the circuit. That would be a tough task for a DIYer to do. Others use a second voice coil to sense the cone movement, but then that sensor will be subject to the same distortions from magnetic field variations that drive the cone, no longer giving an unbiased measurement.

The approach I used is to filter within the feedback loop to avoid the resonance. An integrator can slant higher frequencies downward by 20dB/decade so you can gain almost 20dB of advantage at 900Hz, relative to the subwoofer's intended passband. This will drop the phase by 90° everywhere, though, so you need to be careful to keep the phase from approaching zero degrees at frequencies at which loop gain will still be high.

With the integrator circuit, there will then be a range of frequencies between 200Hz and 900Hz where the gain will be low. In this range, if gain is kept well below 0dB, you can afford some phase shift accumulation, so I used a Twin-T passive notch/lead filter to abruptly kill the loop gain near that 900Hz resonance. A passive Twin-T notch has rather low Q (that is, the notch is not very narrow), which is an advantage in that it need not be very precisely tuned to the frequency of the resonance. Loading the passive notch with a resistor (R12) gives the circuit a phase lead below the notch frequency.

If made with perfectly balanced components, the Twin-T can give an extremely deep notch, but that is not needed for this application. Use of 5% parts should be adequate. This gives a comfortable gain margin while still allowing for about 10dB of loop gain near 70Hz (**Fig. 4**).

Another practical consideration is that you need to keep the power amplifier's output centered near zero volts, and an accelerometer cannot sense the cone position that would result from an offset voltage. So the integrator needs to be a "leaky integrator," that is, one that has a resistor across the integrating capacitor, along with an input coupling capacitor so that the servo board output centers at 0V DC. You can use an op amp to scale the overall loop gain up or down as needed. R8 in **Fig. 5** can provide this adjustment, as the gain will scale inversely with the size of this resistor (or resistor pair).

I implemented the servo circuit (**Fig. 5**) using a CMOS rail-to-rail dual op

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amp, using supply current tapped from the power amplifier supply. Overall circuit impedances are kept high, to keep the topology simple and allow the use of small-size film capacitors. This necessitates the use of CMOS input op amps, though, so don't substitute the op-amp type unless you know just what you are doing!

The resistor (R12) after the notch filter also limits the output voltage swing capability from the circuit, so that the servo circuit cannot significantly overdrive the power amp input. This is done to avoid any long recovery times should the integrator become driven to its limits during error conditions.

Figure 6 shows a block diagram of the servo subwoofer system and illustrates how the added servo board operates in the signal flow of the system. For those wishing to attempt a similar modification on a different powered subwoofer design, the sidebar discusses how to measure loop gains using an audio measurement system.

Also needing attention is the crossover circuit itself, which will still be used ahead of the servo circuit. As originally designed, the circuit includes a high-pass rumble filter section that protects the system from extremely low frequencies, and also adds an EQ peak near 30Hz where the port output dominates in the ported enclosure. While the protection from very low frequencies is still a good idea, the EQ peak is no longer needed or wanted. I reverse-engineered the crossover circuit and devised a simple modification to remove the peak. If you want to live dangerously and don't want the rumble filter, you can remove most of the high-pass behavior as well. Plots of various crossover electrical response results are shown in **Fig. 7**.

To demonstrate how this all works out, **Fig. 8** shows the measured small signal near-field acoustical response results of a modified Sub120 (the Sub100 will have essentially the same shape). Yes, the –3dB point is really at about 12Hz with the high-pass rumble filter disabled. If you keep the high-pass, you'll need to settle for 16Hz. The response ripples around 10Hz are real, by the way, and I don't have a good explanation for them. The distortion will be very high at that frequency (the feedback does not help there where the loop gain is low, and this is, after all, only a 12˝ woofer!), so that may be having this effect.

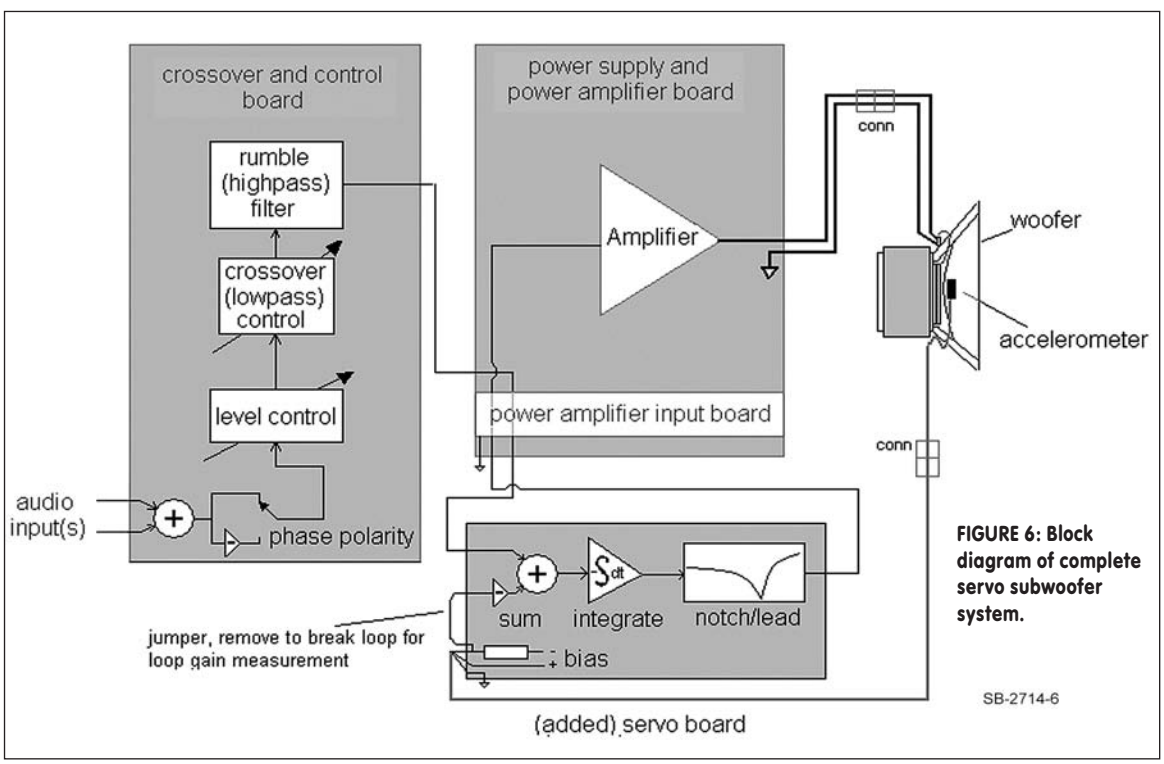

FIGURE 6: Block diagram of complete servo subwoofer system.

WHAT YOU WILL NEED

The accelerometer I used in this project is MSI's ACH-01-03 unit, which is a particularly nice, wideband, inexpensive surface contact piezo accelerometer, with a suitable

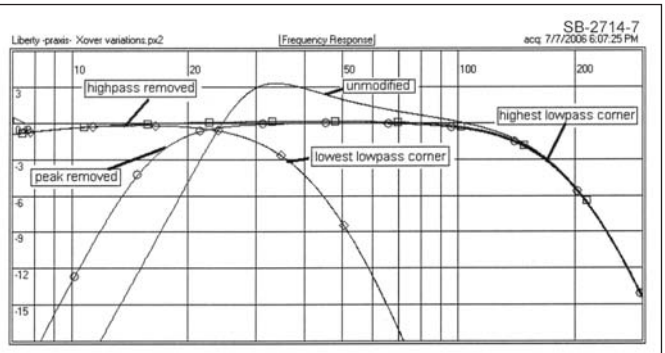

FIGURE 7: Measured subwoofer crossover response curve in several mod variations and at the extremes of the low-pass corner adjustment control.

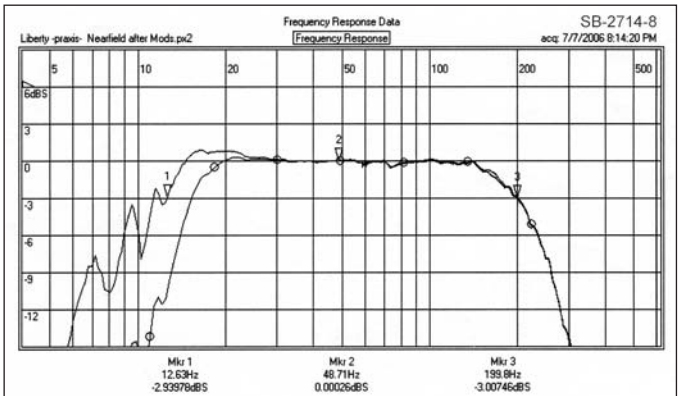

FIGURE 8: Response curves of modified subwoofer, with and without rumble filter (low-pass corner set to maximum).

limp cable attached. At this writing, you can obtain it for about $20 from Mouser (www.mouser.com), though the same unit now costs $30 from Digi-Key (www.digikey.com), so the price may be rising. Other parts and supplies you need are listed in **Table 1**.

I used many parts scrounged from my spare parts boxes, but have listed commercial replacements for any that are not easily found. You can probably substitute for many of these parts, but I recommend you stay with the same type accelerometer and op amp. Using physically larger parts could also require that you use a larger circuit board for the servo board. I made my servo board using a small Radio Shack pad-per-hole breadboard, wired point-to-point by hand. The circuit is not very complicated, so I did not lay out a custom PC board for it. But you are welcome to do so if you wish.

Note that R8 may consist of a single 330k resistor, or if you plan to adjust the loop gain values experimentally (for which a measurement system is recommended), you can substitute a 1MEG trimmer potentiometer in series with a 47k fixed resistor in place of the single 330k resistor.

You will also need some basic tools (drill with some bits, soldering iron, solder). And a Torx-type T15 screwdriver bit to remove and reinstall the screws that hold the Sub100 or Sub120 together.

INSTRUCTIONS

1. After you have obtained a Sub120 (or Sub100), first connect it to your system and verify that it is working well and has no buzzes or rattles. You need to have good working hardware to start with, and later steps could be too late to find out about any problems. Doing this is very important before going to step #3.
2. Bid a fond farewell to your sub's manufacturer's warranty, which will no longer be with you after the next step. You are going to be putting holes into and gluing things onto the woofer and plate amplifier and soldering on the unit's circuitry, so you can't expect Dayton Audio or Parts Express to honor the warranty after that. Welcome to DIY audio!
3. Using the T15 screwdriver, remove the woofer from the front and the plate amp from the back of the enclosure. While doing this, keep track of where the screws go, because there are several different types that aren't interchangeable! You will need to pull the push-on contacts from the woofer terminals.

   The plate amplifier has a plastic well sealing its back (so the box doesn't leak), which you can detach from the plate itself by unscrewing four screws and unplugging a connector that is inline with the wires that run to the woofer. That connector is wrapped in foam, which you will need to cut away to access. In the lower section of the plastic well, drill a hole just large enough to pass the diameter of the cable on the accelerometer.
4. Seal the two port openings of the box. You don't need to remove the port tubes, but you do need to make good tight seals on the portholes—leaks are bad.
5. Use a battery (A, AA, C, or D cell) to determine the polarity of the terminals on your woofer. Momentarily connect one woofer terminal to each end of the battery using a wire to complete the current path. When connection of the battery makes the cone push out away from the magnet, then the woofer terminal that is connected to the [+] (protruding button) terminal of the battery is the [+] speaker terminal. Mark that terminal "red" with the indelible marker (the [+] terminal will connect to the red speaker wire). If you get this backwards, your system will become a high power oscillator, so be careful!
6. Clean the woofer dust cap with rubbing alcohol on a piece of cloth to remove any oil or dust. Using a ruler, locate the center of the woofer's dust cap, and mark the location with the indelible marker.
7. Find the edge of the dust cap that is *opposite* from the edge where the voice coil wires exit in back of the cone, and mark that spot so you can identify it from the front side of the dust cap. You will be routing the accelerometer cable through the woof-

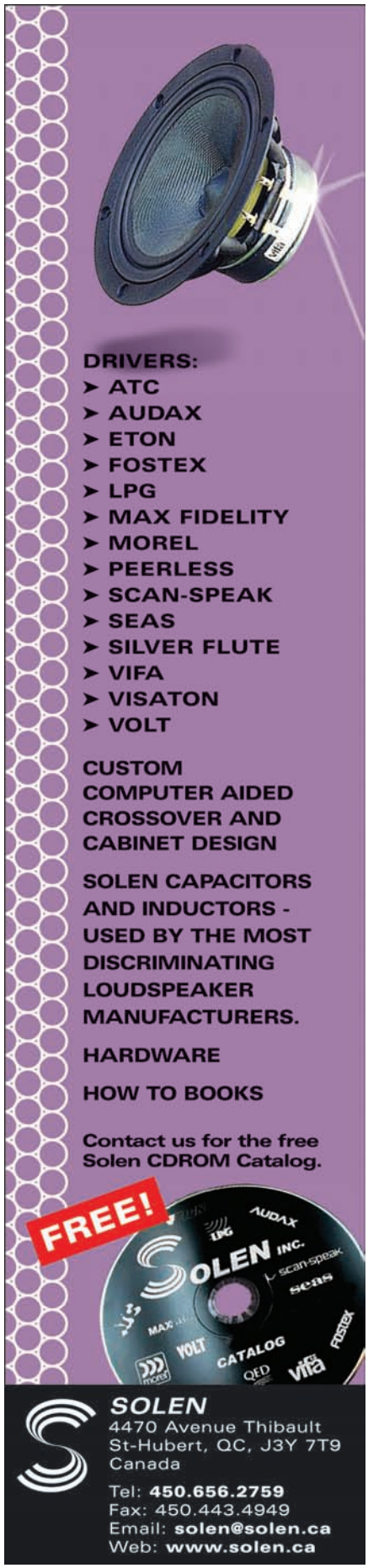

PHOTO 3: Gluing the accelerometer cable to the woofer cone.

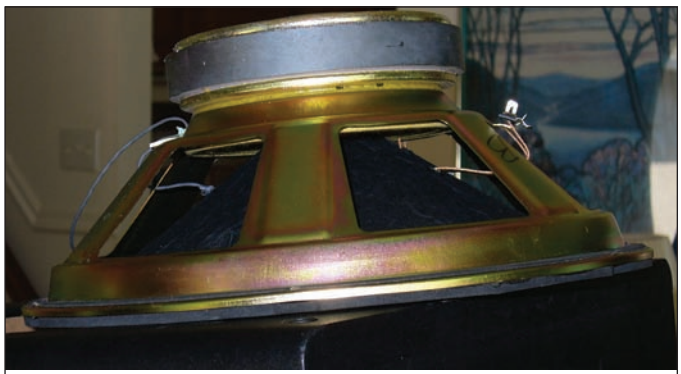

PHOTO 4: Flexible mounting of the accelerometer cable (left) to the woofer basket.

er cone there. Drill, poke, or burn a small hole, just large enough to pass the accelerometer cable, through the dust cap and cone about a quarter inch inside from the edge where you marked.

8. Cut the connector from the accelerometer cable leaving the accelerometer cable as long as possible. Apply the glue activator over the area of the dust cap where the accelerometer will mount and let it dry a few seconds. Clean the ceramic back surface of the accelerometer with the alcohol and cloth, then use a liberal coating of the cyanoacrylic gel glue to attach the accelerometer to the marked center of the dust cap, with the cable going out toward the hole you made for it. Be careful to *not* get the glue on your fingers, or you'll become bonded to the dust cap, too!

Position the accelerometer properly when you first contact it to the dust cap, because the glue will harden very quickly and you won't get a chance to reposition it. Route the cable through the hole, and seal the hole around the cable with the silicone glue. Also use the silicone glue sparingly to hold the cable section that is running to the hole in the cone, to the cone surface (**Photo 3**) so that the cable will not buzz or rattle.

9. Loop the cable in back of the woofer cone so the cone is free to move without interference from the cable. Put a 1″ piece of foam tape at the edge of the basket near where the cable comes out. Then route the cable over that foam tape, and then cover the cable with another piece of foam tape, so the cable is sandwiched between two layers of foam tape and attached to the basket (**Photo 4**).
10. Determine how and where you will mount your servo board. **Photo 2** shows my mounting location, which is near the points where the servo board needs to connect. If you mount it there, though, you will need to keep the board small so that the plate amp can still mount within its well.

I used one of the holes at the edge of the pad-per-hole circuit board to mount onto one of the existing screws that hold down the power

TABLE 1: PARTS LIST FOR SUB100/120 MODIFICATION.

Reference	Description	Part Number	Notes
–	Powered Subwoofer, Dayton Audio Sub-100 or Sub-120	Parts Express #300-633 or 300-635	10″ woofer or 12″ woofer, with internal crossover and amplifier
–	Accelerometer, piezo (MSI)	ACH-01-03/10 (Mouser #824-ACH-01-03/10)	$20 each (or $30 each at Digi-Key)
C1, C2	Tantalum bead capacitor, 4.7µF 10V	Mouser # 80-T350A475K010AT	
C3	Film capacitor, 1µF 50V	Digi-Key #P4675-ND	Film type only, small size
C4	Film capacitor, 680pF	Digi-Key # ECQ-B1H681JF	Film type only
C5	Film capacitor, 0.033µF 5%	Digi-Key # ECQ-V1H333JL	
C6, C7	Film capacitor, 0.018µF 5%	Digi-Key # ECQ-V1H183JL	
D1, D2	Zener diode, 5.1V	Digi-Key # 568-1671-1-ND	
R1, R2	Resistor, 220k 5%, 1/4W		
R3	Resistor, 1M 5%, 1/4W		
R4, R9, R10, R11	Resistor, 10k 5%, 1/4W		(R11 is used to modify the crossover board)
R5, R6	Resistor, 4.7k 5%, 1/2W		
R7	Resistor, 4.7M 5%, 1/4W		
R8 (or R8a and R8b)	Resistor, 330k 5%, 1/4W		If making loop gain adjustable, use 1M miniature trimmer in series with 47k fixed resistor.
R11	Resistor, 4.7k 5%, 1/4W		
R12	Resistor, 2.7k 5%, 1/4W		
U1	CMOS R-R output op amp, TLC2272ACP	Digi-Key # 296-7109-5-ND	
–	8-pin DIP socket for U1, solder tail		
–	Circuit board or protoboard for servo circuit	Radio Shack #276-148	Can use this board part number if parts are kept small.
–	Mounting hardware for servo board		As required for the servo board construction technique used.
–	Connector set 9-pin D-sub type, 9 pin, one each male and female		(Optional for Accelerometer quick-disconnection.)
–	Assorted wire and cable		
–	Gel-type cyanoacrylic "super" glue and activator		
–	Silicone II Household Glue (GE)		Fast curing
–	Adhesive foam tape (3M)		For looping the accelerometer cable and attaching to woofer basket

amplifier main board, and added a second standoff terminal to hold down the opposite corner of the board. I needed to break off a corner of the board around one of the holes so it would not interfere with another screw on the power amp board. The servo board is attached then at only two points, but you can use silicone glue after all is working to keep it stable and rattle-free.

11. Remount the woofer, connecting its terminals to the wires that come from the plate amplifier's plastic well (being careful to match the red wire to the red terminal as you determined in step 5!), and with the accelerometer cable fed through the extra hole you made for it in the plate amplifier's well. Seal around the cable at the hole with silicone glue.
12. On the power amplifier input board, unsolder and remove the jumper "JP4" that is near the ribbon cable at the top (**Photo 5**).
13. Modify the crossover board as shown in **Photo 6**. Cut the trace where shown and patch a 10k resistor (R11) across the two trace pieces that were separated. This change will remove the high-pass EQ peak, giving the crossover filter a flat top.

If you want to remove the rumble filter, add the two optional jumper wires where shown. But don't remove this rumble filter if you ever play vinyl records, because record warp and tonearm resonances will throw

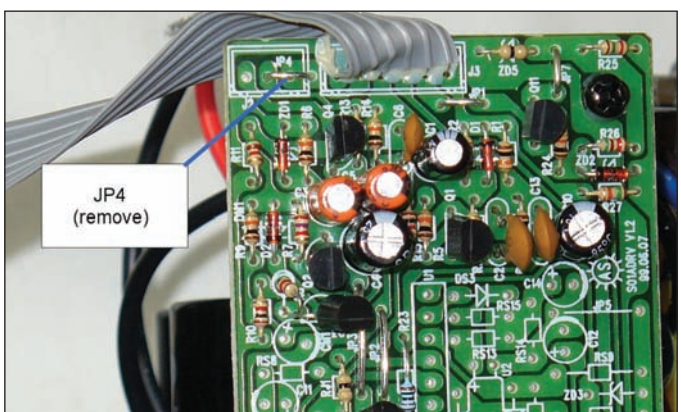

PHOTO 5: JP4 location on power amplifier input board.

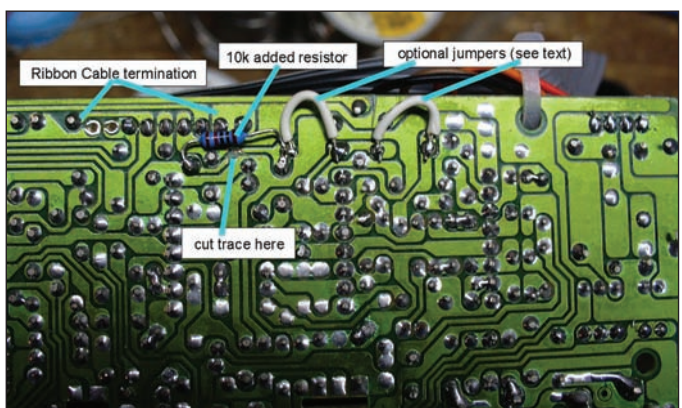

PHOTO 6: Modifications to the crossover board.

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Measuring Loop Gain and Phase

You can measure the loop gain and phase of the Simple Servo system if you have access to a measurement system that can plot relative voltage gain and phase shift. The stimulus from the test gear should drive the servo board (via a level control) at the point where the feedback signal from the accelerometer normally connects. To determine the loop response without the servo processing, as shown in **Fig. 1**, drive the amplifier input directly from the stimulus. The sense or acquisition input of the measurement system then analyzes the signal that comes from the accelerometer and compares its magnitude and phase to that of the applied stimulus. The dB difference in magnitude is the loop gain and the difference in phase is the loop phase. Both of these values will normally vary greatly with frequency.

First, you must temporarily break the feedback loop between the accelerometer and the input summing network of the servo board. A jumper that can be removed to accomplish this is indicated on the parts layout between R1 and R2.

Removing the jumper leaves biasing resistor R1 connected to the accelerometer so it still powers the sensor and removes R1 from the summing input. Keep the loading on the accelerometer light, as its source impedance is relatively high (approximately 20kΩ). Make the test at the lowest practical drive level, because the total amplifier gain will be considerably higher than normal with the feedback loop disrupted like this.

As described in the text, the loop gain must never approach 0dB (or higher) at any frequency where the loop phase approaches 0. Note that a phase curve that jumps from near 180 to near –180° probably is not crossing zero degrees on the way, as 180° and –180° are really the same angle—think of phase as being represented by positions on a circle. You should also arrange that the phase does not get close to zero degrees at any frequency where the gain is 0dB.

The amount that the gain lies below 0dB at each zero degree phase crossing is known as "gain margin." The amount that the phase differs from zero degrees at each 0dB gain crossing is called "phase margin." As a good rule of thumb, try to keep 8dB or more of gain margin and 45° or more of phase margin on your loop gain curve, to account for possible component drift or parameter change with drive level. You can adjust overall loop gain by varying R8. To selectively change the gain and phase at different frequency ranges, you will need to adjust or add sections such as high pass or low pass filters, integrators, differentiators, or notches. Your goal is to maximize the loop gain over the operable frequency range while still maintaining sufficient gain and phase margin at any 0° or 0dB crossings on a loop gain plot. A good modeling program is essential for optimizing the network.

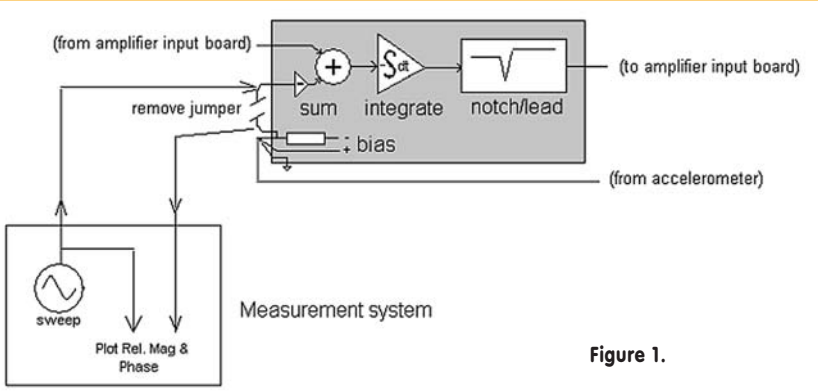

Figure 1.

your woofer cone all over without it! If in doubt, skip the jumpers and leave the high-pass filter in place.

14. Cut the wires that run to the speaker

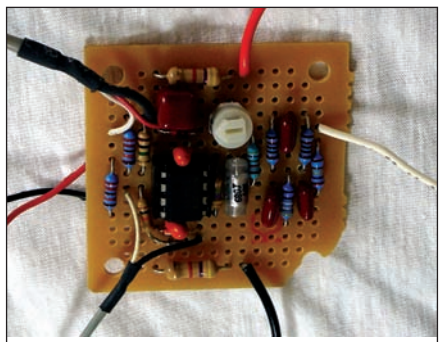

PHOTO 7: Photo of my servo board.

PHOTO 8: Wiring between the servo board and the power amp input board.

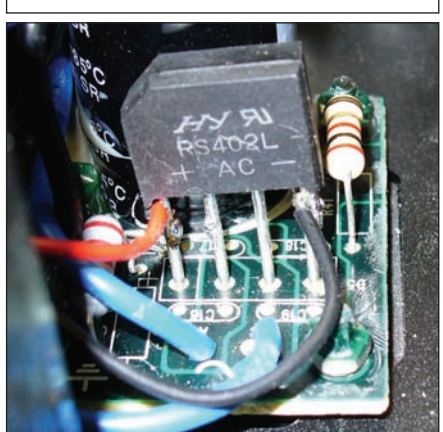

PHOTO 9: Wiring of the power wires to the rectifier block on the power amplifier board.

connector from the power amplifier board, and insert about 15″ of moderately heavy wire to extend the length between the power amplifier board and that connector (be careful to not swap the wires!). This lets you test-run the amplifier while it is setting on top of the enclosure, without it being down in the plastic well during initial startup and testing.

15. Build your servo circuit board, following the schematic in **Fig. 5**, using a socket for the CMOS op amp (don't plug the op amp in yet, to avoid handling the static-sensitive chip unnecessarily until it is needed). The banded ends of the zener diodes D1 and D2 are the cathodes (the end with the crooked bar in the schematic symbol). Add connection wires for the input signal, input ground, output wire, and the two supply wires, and about 12″ of three-wire cable (or twisted wires) that can connect to the accelerometer cable. I used a set of 9-pin D-sub connectors to provide a quick-disconnect capability for the accelerometer cabling.

    I just used the resistor and capacitor leads, to run between the pads on the back of the circuit board. Double-check your connections and diode, capacitor, and IC polarities, and make sure there are no unintentional shorts between pads.
16. If you used a trimmer as part of R8, set it so the total resistance of R8a and R8b is 330kΩ, as measured with an ohmmeter. Install the IC U1 into its socket. **Photo 7** shows my servo board at this stage.
17. Mount the servo board to your plate amp and connect its wires as shown in **Photos 8** and **9**. The input, ground, and output wires go to the area where JP4 was removed. The power supply pickoff wires are most conveniently connected at the bridge rectifier block on the main power amp board, as shown in **Photo 9**, with the polarities as marked on the rectifier.
18. Double-check all of your wiring. Mistakes can be loud and/or smoky.
19. Put the plate amp on top of the sub, and temporarily put the plastic well into the opening at the back with several screws. Connect the extended cable and connector from the power amp to the connector that goes to the speaker. Connect the cable from the accelerometer to the extender cable that you added for it on the servo board.
20. Now comes the moment of truth. Use a switched outlet strip to apply power to the sub box with the sub's power switch set to "ON." Use the switched strip so you can switch it off quickly if things become too exciting. The first turn-on transient can be energetic (this is also true of these subs before modification). But after that, the woofer cone should settle down and the unit should not oscillate. I have had the Sub120 briefly oscillate due to accidentally miswired speaker polarity, and the driver survived the ordeal. But I can't guarantee you would be that lucky.
21. If all went well in the previous step, apply a music input signal to the input of the crossover and make sure that the sub plays at low level. It won't sound like much by itself, but you should be able to tell if it is

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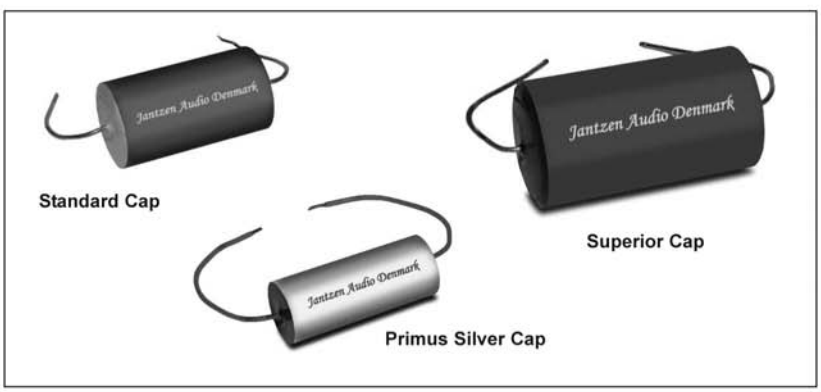

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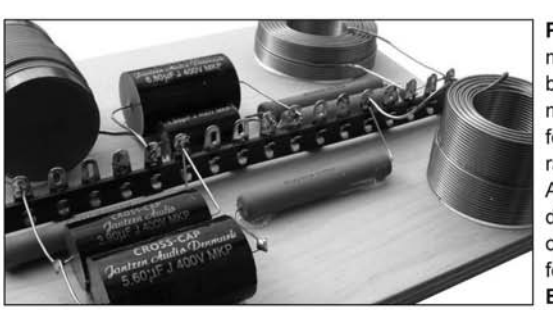

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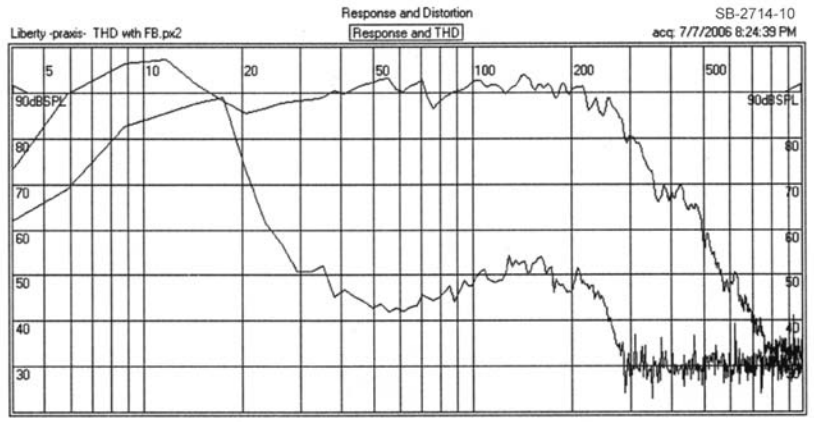

FIGURE 9: Response (top) and distortion (bottom) at 20″ and 90dB SPL.

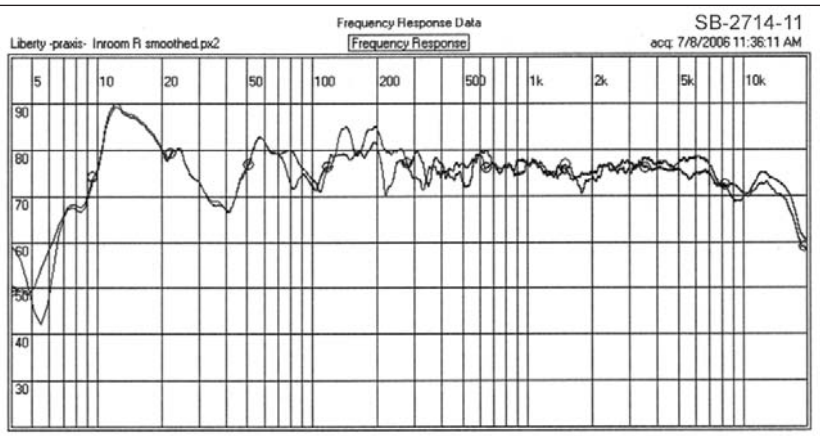

FIGURE 10: An in-room response, 1/6th octave smoothed. Modes dominate at low frequencies.

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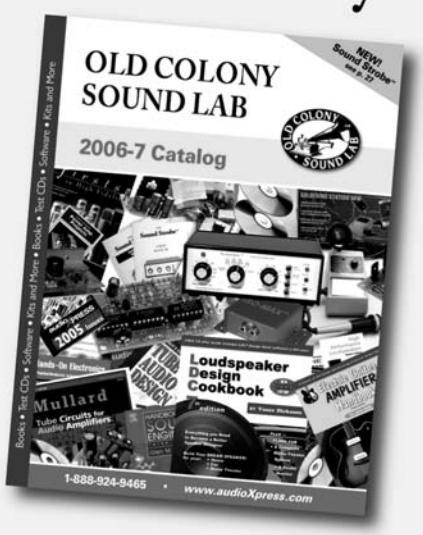

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working.

Then if that is successful, reassemble the plate amplifier in its well and into the enclosure using all screws to prevent air leaks and wrap cables to keep them from getting pinched. Make sure that any connectors you added do not accidentally short to other circuitry. Tape metal parts up, or wrap in pieces of foam rubber before putting the plate amp into its well, to avoid shorts and rattles. Then you are ready to listen.

USING THE SUB

There are numerous methods you can use to adjust the settings on the sub. If you have a computer and a good microphone such as Mitey Mike, you can use the PRAXIS software (from www.libinst.com) in its "free" mode as an RTA at 65k FFT size and ⅙th octave resolution, with pink noise stimulus to check overall response and level setting. Or you could use warble tones and an SPL meter. Or you can try adjusting by ear, though expect to spend considerable time getting it right that way.

If you are adjusting by ear, remember this rule of thumb: If your attention is drawn to the location of the subwoofer, it is too loud. The sound should always seem to be coming from the main speakers, never from the sub. The subwoofer should only add weight and extension, but should never dominate the sound. With some music that has no deep bass, the sub will and should do nothing.

ADJUSTING EXPECTATIONS

OK, you now have a subwoofer that goes down to very low frequencies with an extremely flat response. All is perfect, right?

Well, not entirely. You should consider the nature of low bass frequencies.

First, I haven't discussed amplitude limits. Yes, the woofer can be flat down to about 12Hz at measurable levels, but it won't realistically play tones at audible levels there. The woofer just can't move the amount of air needed to reproduce earthquakes or dinosaur footsteps. **Figure 9** shows a response and harmonic distortion plot of the modified Sub120 at 90dB SPL about 20″ from the cone. Distortion climbs quickly near 20Hz. By 16Hz, the distortion is at about the same

level as the driving frequency.

Second, while the near-field response of the sub is very flat, that is really no indication of what its response will be in the room. At frequencies this low in domestic rooms, the sound is supported by standing wave modes, the pattern of which will depend on the room dimensions and the placement of the sub and of the listener. The response from a single subwoofer is very unlikely to be anything resembling a flat response.

The response (two channels superimposed) in my listening room as measured at the listening position, for example, is shown in **Fig. 10**. I hope to still do better with some more experimentation in placement of the sub, but it is obvious that the room response greatly dominates over the subwoofer response. However, note the large excess of energy at around 11Hz from the room lift at low frequencies. Maybe I'll be able to get dino footstep effects after all . . .

In general, the best solution to both problems is not to just use a better or more powerful subwoofer, but to use multiple smaller subwoofers such as these. By placing several mono-connected identical subs placed apart within the room, various modes could be traded off to get a more uniform response (which a lone kilowatt or kilobuck sub could not do), and the use of multiple subs would at the same time boost your overall output level capability.

But that being said, I haven't yet overtaxed one of these woofers when playing music at my normal levels. But home theater use might be another matter. *aX*

AFTERTHOUGHTS

In reflecting on the completed article, I noticed that it would be easy to extend the idea to one or more slave subs by sending them the servo output. Only the original unit would need the servo circuit and accelerometer. However, the slave sub or subs would need to have their ports sealed, jumper JP4 removed, and the left low-level input connector wired to the power amp input.

It would be a good idea to buy as many subs as you want on the same order. This will help ensure a better match between drivers as they will likely be from the same batch. However, sealed enclosures are rather forgiving in this respect so a slave sub purchased later will probably work fine.

*A servo modification kit is available from Old Colony Sound Lab (**www.audioXpress.com**, 1-888-924-9465). Price, which is effective through 12/31/06, is $133. The kit includes a circuit board and all electronic parts, a 3˝ length of adhesive backed foam tape, a tube of Silicone II glue, and a package of gel-type "super" glue.*

To accommodate the option of using one or more slave subs, the servo circuit has been modified from the original by including an output buffer amplifier. The additional parts, a new circuit diagram, and parts list will be included in the kit along with construction details to complement the original article.

NOTICE

ATTENTION, READERS

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