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Dr. Joseph D'Appolito has been working as consultant for Usher Audio since early 2000. A world renown authority in audio and acoustics, Dr. D'Appolito holds BEE, SMEE, EE and Ph.D. degrees from RPI, MIT and the University of Massachusetts, and has published over 30 journal and conference papers. His most popular and influential brain child, however, has to be the MTM loudspeaker geometry, commonly known as the "D'Appolito Configuration," which is now used by dozens of manufacturers throughout Europe and North America.

Dr. D'Appolito designs crossover, specifies cabinet design, and tests prototype drivers for Usher Audio, all from his private lab in Boulder, Colorado. Although consulting to a couple of other companies, Dr. D'Appolito especially enjoys working with Usher Audio and always finds the tremendous value Usher Audio products represent a delightful surprise in today's High End audio world.

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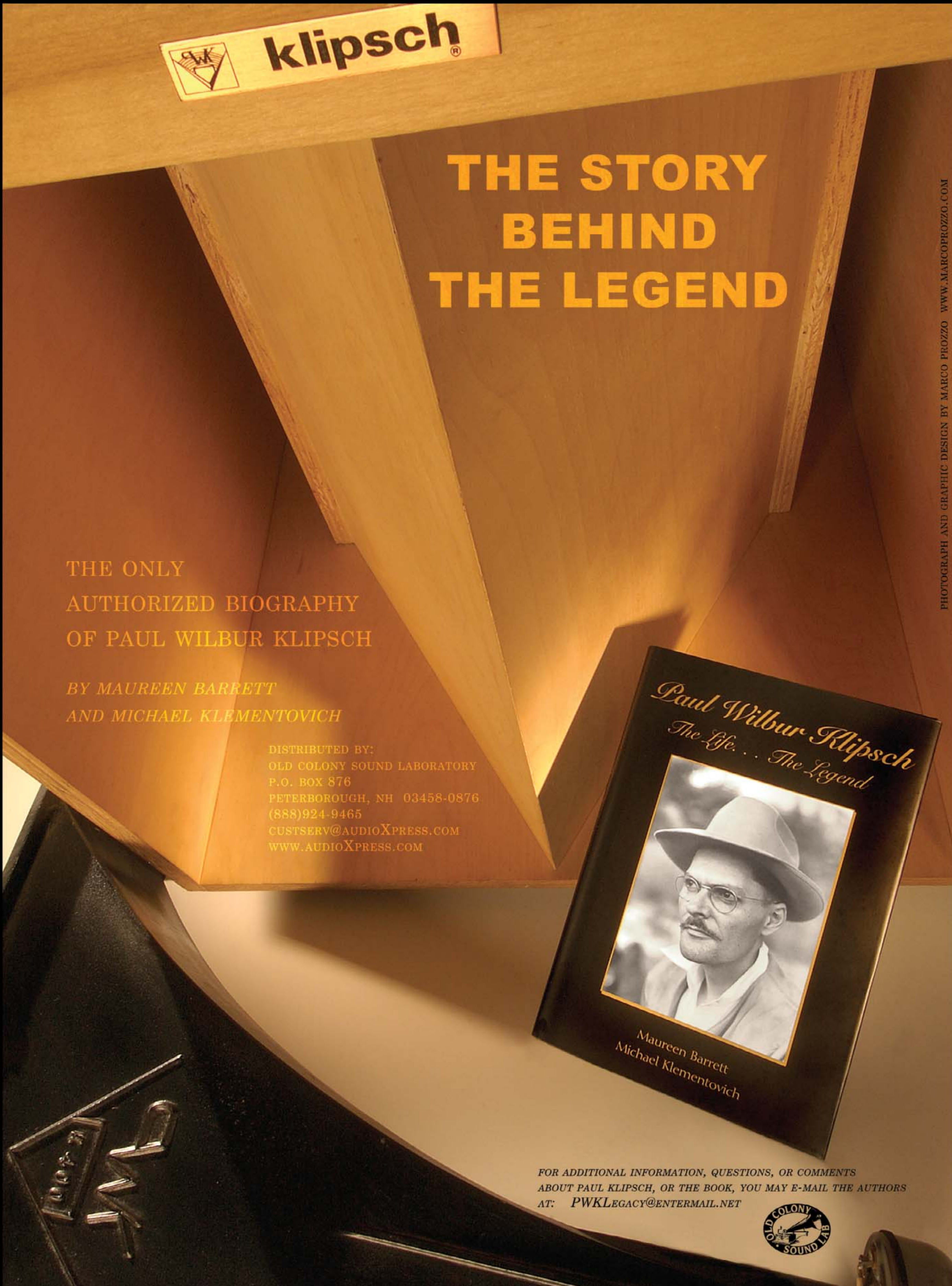
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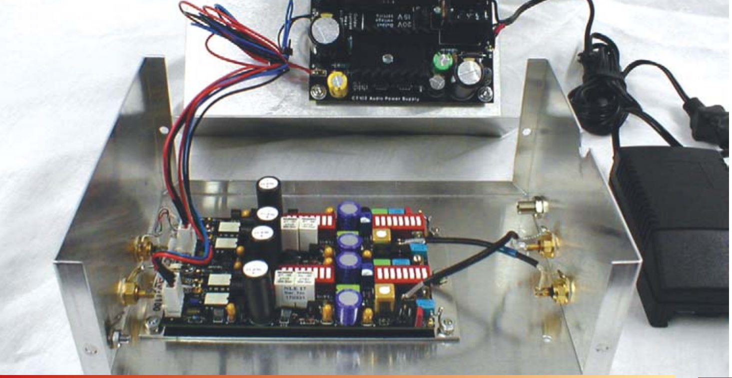

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DEPARTMENTS

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solid state · tubes · speakers

The peculiar evil of silencing the expression of an opinion is, that it is robbing the human race; posterity as well as the existing generation; those who dissent from the opinion, still more than those who hold it.

JOHN STUART MILL

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Zen Variations 7: More Fun with Son of Zen and Super-Symmetry

Still keeping it simple while maintaining good amp performance, these circuits dramatically raise the efficiency of the Son of Zen.

By Nelson Pass

One of the performance issues raised by the original Son of Zen (*Audio Electronics* 2/97) was its efficiency figure, which was charitably described as 4% (500W in, 20W out). You may recall that this was dictated by the original requirements—no feedback, no capacitors in the signal path, and a single gain stage.

"Zen Variation 6(ZV6)" (*aX* 5/04) relaxed the requirements on feedback and capacitors in order to provide a tutorial exercise about "super-symmetric" feedback. The performance in distortion and output impedance was improved, but only slightly so for the efficiency, largely because I used most of the original circuit.

In the first part of this article, I am going to raise the efficiency from about less than 4% to nearly 6%, simply by eliminating the negative power-supply rail and biasing the differential gain pair with a constant-current source. This will also give improved distortion performance with a single-ended signal source over the circuit of ZV6.

In the second part of this article, I will additionally raise the efficiency to over 16% by driving coupled inductors instead of resistors. This will nearly quadruple the efficiency of the original Son of Zen (SOZ), but with much better performance in all areas except for the input impedance.

Of course, it is also a slightly more complex circuit. And keep in mind that the Zen and its brethren are all explorations in achieving good amplifier performance as simply as possible. What constitutes "good" is observed from both an objective (measurement) and a subjective (listening) viewpoint. It is my opinion that the simpler the circuit, the more similarity there tends to be between these two, but not always.

BIASING WITH AN ACTIVE CURRENT SOURCE

The transistors of the original Son of Zen were biased up from the negative supply and did not contribute to the available output of the amplifier in a direct way, so there was considerable waste of energy. They needed to see relatively high impedance in the biasing network and they also needed to run at the full output current, and so they ran near the full rail voltage and used up about half the power. An active current source can operate at quite low voltages (as low as 2V for a power MOSFET without significant degradation). At low voltage it can carry the full bias current of the amplifier, dissipate a much smaller amount of energy, and still offer a much higher impedance than the original network.

Figure 1 shows such an arrangement applied to a Son of Zen, along with the feedback networks R1-R4 and P1-P2 that I applied in ZV6. I am going to call it ZV7-R. Q3 is the current source, and it sinks about 7.5A of bias current split equally through Q1 and Q2, which are the gain transistors for

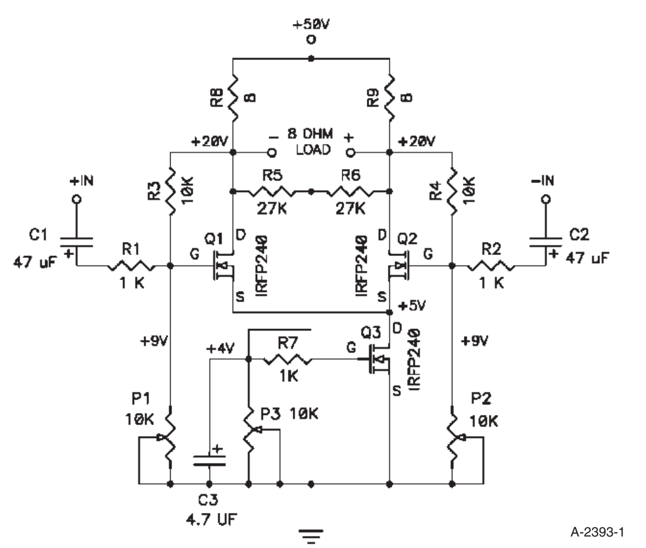

FIGURE 1: The ZV7-R.

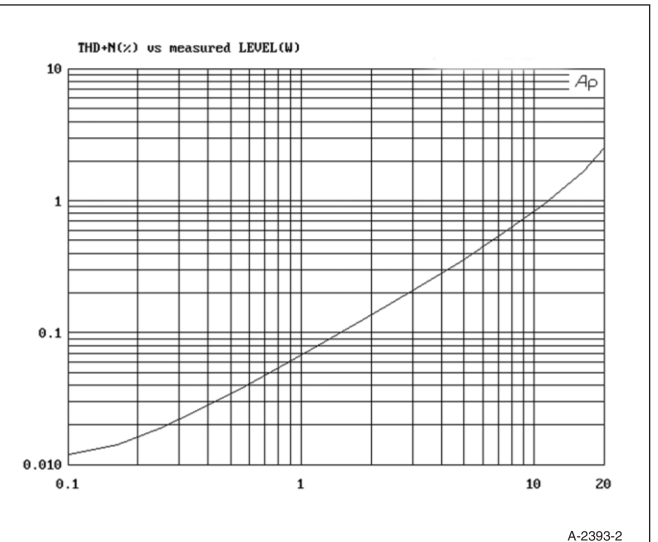

FIGURE 2: Distortion vs. output power into 8Ω.


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this single-stage circuit.

The gate of Q3 is fed a control voltage by a network of resistors R5, R6, R7, and P3. This network senses the DC output voltage on the drains of Q1 and Q2, and this is adjusted by the value of P3 so that the drains of Q1 and Q2 are held at approximately 20V DC. Since the outputs of these transistors have their signals out of phase, the junction of R5 and R6 sees just the common voltage, which is the DC figure.

If the DC value goes up, then the voltage on the gate of Q3 goes positive and it conducts more current, and the outputs of Q1 and Q2 go back down and are thus held fairly constant. C3 is included for some filtering to avoid any audio AC signal or supply noise from making its presence known at the gate of Q3. The circuit works quite well without it, but has a noticeably higher noise floor.

R7 is the ever-present gate resistor for Q3 which prevents parasitic oscillation. Most of the time I have used values of 221Ω for R7, but in this case I found that some inductive loads could induce oscillation. This was cured by increasing the value of R7 to 1kΩ.

As mentioned before, the voltage across Q3 can be as low as 2V, but the values of P1 and P2 have been set so that 5V appears across Q3. This is to allow margin for when the amplifier is driven by a single-ended input. In this case, one input is driven and the other is grounded and you see some voltage swing occur on the gates of Q1 and Q2, and thus also on the drain of Q3. By setting this voltage at 5V, variations as much as ±3V can appear on the drain of Q3 before the voltage across Q3 dips below 2V and distortion sets in.

If you are running the amplifier with balanced inputs, then you can set this voltage lower, as the variation at the drain of Q3 will only be a volt or so. In this case you can pick up slightly greater efficiency by running the drain of Q3 at 3V or so by lowering the values of P1 and P2. Feel free to experiment, as these figures are not critical, and you probably won't break anything.

P1 and P2 also help adjust the differential DC output. While this has been set at 20V by P1, you must vary the differential DC value a bit to get low DC offset between the two outputs, as this is what the loudspeaker will see, not the 20V. You should readjust these after amplifier warm-up and reexamine them after the amplifier has been broken in for a while. My standard for DC offset is 50mV or less, and I have been known to put up with 100mV.

The total draw of this particular circuit is 375W, and most of this appears across the 8Ω resistors R8 and R9,

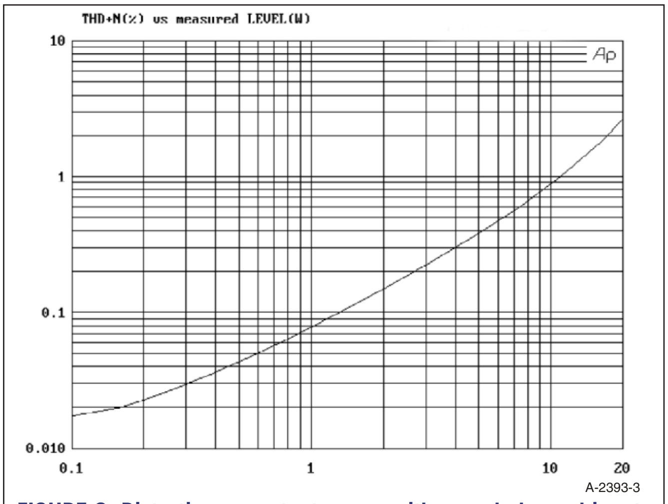

FIGURE 3: Distortion vs. output power with an unbalanced input.

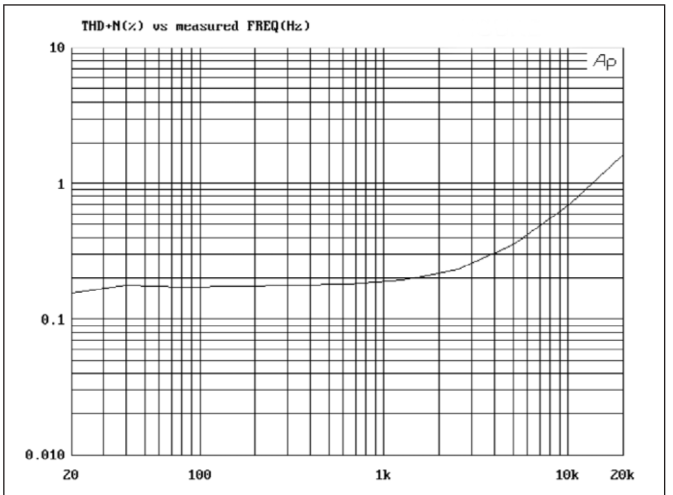

FIGURE 5: Distortion with single-ended input.

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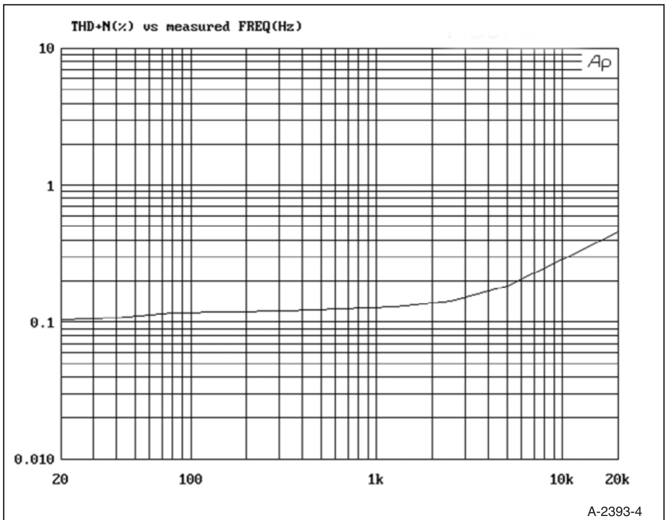

FIGURE 4: Distortion vs. frequency at 2W with a balanced input.

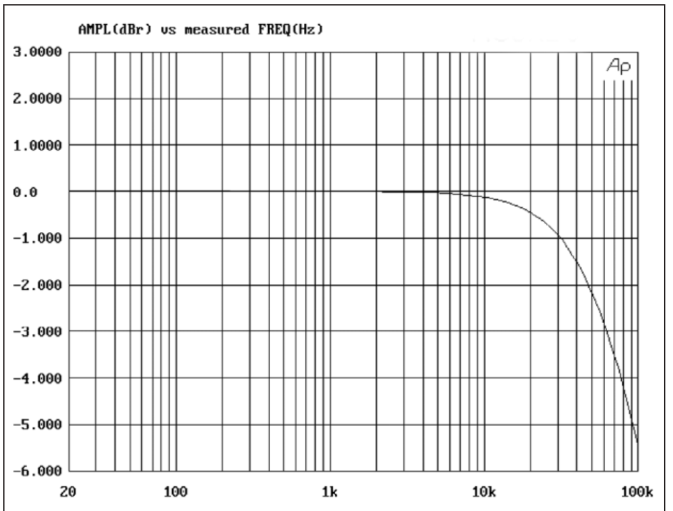

FIGURE 6: Frequency response.

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which experience about 112W each. Q1 and Q2 will dissipate about 56W each, and Q1 will see about 37W.

As with all the other Zen projects—and Class A amplifiers in general—adequate heatsinking is essential. The power resistors can take more heat, so it is often advantageous to give them separate heatsinks to operate at higher temperatures than the transistors, which you want to keep in the 60° C range. This would be achieved by heatsinking with a thermal resistance of about 0.15° C per watt.

PERFORMANCE

The gain of the amplifier came in about 2dB higher than ZV6 at 14dB, and I did not adjust this out. It is reflected in the slightly lower damping factor (2.25) and slightly higher distortion numbers at the higher frequencies. Of course, you can compensate this back down by increasing R1 and R2 to 1.25kΩ, (or even more if you like).

Figure 2 shows the distortion versus output power into 8Ω for this circuit driven by a balanced source at 1kHz. You will note that it bears a strong resemblance to the results of ZV6, both being big improvements over the original Son of Zen.

Figure 3 shows distortion versus output power with an unbalanced (single-ended) input where the other input has been grounded. Note that, unlike Son of Zen or ZV6, there is virtually no degradation in this curve between balanced and single-ended inputs, and that the noise floor is quite a bit lower than the Son of Zen.

Figure 4 shows distortion versus frequency at 2W with a balanced input, where the distortion slowly climbs above about 3kHz. As noted earlier in this series, this is due to the nonlinear capacitance of the MOSFETs, and is a little higher than ZV6, partly due to the higher gain figure. If you adjust the gain downward, it comes out about the same.

Unfortunately, this does not hold as true for a single-ended input, where the curves are no longer identical, and you see greater distortion than with the balanced case—about three times as much at 20kHz. In and of itself, this is not a big deal, but it does point out one of the advantages of balanced drive, particularly in single-stage circuits, where they can use all the help they can get. This is shown in *Fig. 5*, where you have roughly the same performance as ZV6 (again accounting for the gain increase).

Figure 6 shows the frequency response, which is identical for both balanced and single-ended inputs. It shows –0.5dB at 20kHz and –3dB at 60kHz. This is not as wide as the bandwidth of the Son of Zen, but there it is. If the ultimate in high-frequency response is your goal and your source impedance is low, then the original may be better suited.

As with ZV6, the input impedance of the circuit is approximately 3kΩ balanced, and 1.5kΩ unbalanced, varying slightly depending on the MOSFETs and the loading. Most preamp circuits will drive this, particularly the Bride of Son of Zen (*Audio Electronics* 5/97), or you can easily apply the input buffer transistors found in Zen Variations 4 (*aX* December 2002), which can get you up to 100kΩ balanced.

Keep in mind that these projects are intended as tutorials (of a sort) and usually you should be able to apply ideas you see in one circuit to another. I calculated at least 128 variations of the single-stage concept, but I am only presenting the most interesting and educational. It is up to you to play mix-and-match with the ideas, or as they often said in my college textbooks, "This will be left as an exercise for the reader."

Figure 7 shows the input common-mode rejection of the circuit, which is a pretty consistent −50dB across the audio band. This is typical of all the Son-of-Zen-type circuits (not really much to say here, but I threw the graph in anyway).

INDUCTIVE LOADING

One of the more intriguing possibilities for a Son of Zen with feedback is loading the outputs with inductance to the positive rail instead of those big 8Ω resistors. Because inductors dissipate little energy and can provide much higher voltage swing, you expect them to dramatically increase the efficiency of this circuit, and so they do.

The original Zen and other nonbalanced amplifying stages have some difficulty doing this because the high DC current which must pass through the inductor tends to saturate the magnetic cores found on high-value inductors. I have built a Zen with a 1H coil (alright, a 1000′ spool of MWS magnet wire), and it worked great. However, with a balanced circuit like SOZ, if you use two inductors magnetically coupled (or one center-tapped inductor), the DC currents can be made to cancel magnetically, leaving only the AC component.

The obvious candidate here is a transformer with either two parallel primary windings or two parallel secondary windings, or one center-tapped secondary. I simply went out into my shop and snagged some samples of ordinary AC power transformers and plugged them into the circuit of *Fig. 8*, which I will call ZV7-T.

Here you see basically the same circuit as *Fig. 1* with a pair of coupled coils replacing the pair of 8Ω resistors. Note also that the bias circuit for Q3 has been altered so that it no longer looks at the DC output, which is going to be almost the value of the DC supply. If you track against this voltage, you will find the bias wildly wandering with the value of the supply, and that would be "double-plus ungood," as we used to say in 1984.

Instead, use R5 to take current from the positive supply to bias up a 9.1V zener diode as a voltage reference.

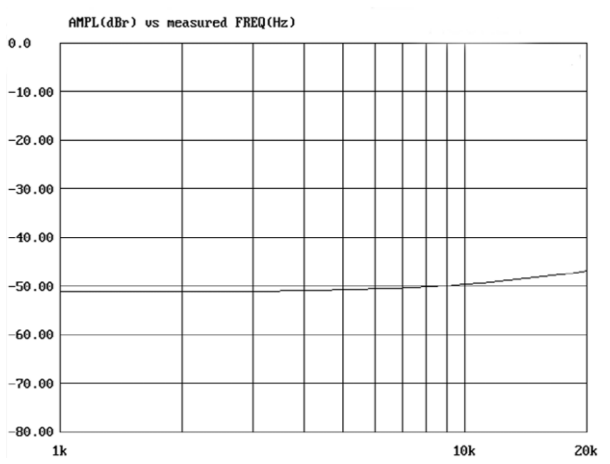

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FIGURE 7: Input common-mode rejection of the circuit.

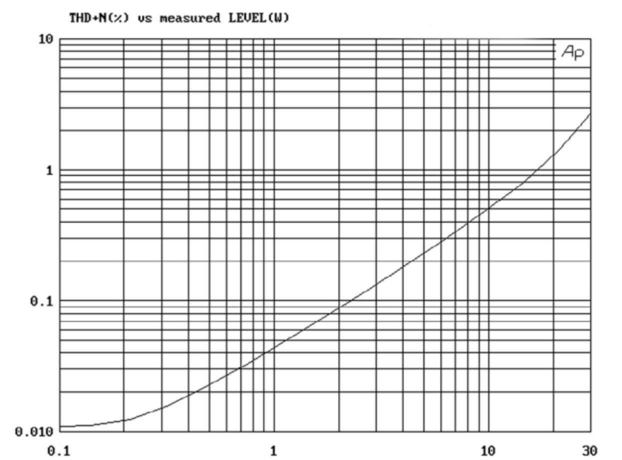

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FIGURE 9: Distortion curve to 30W into 8Ω with balanced input at 1kHz.

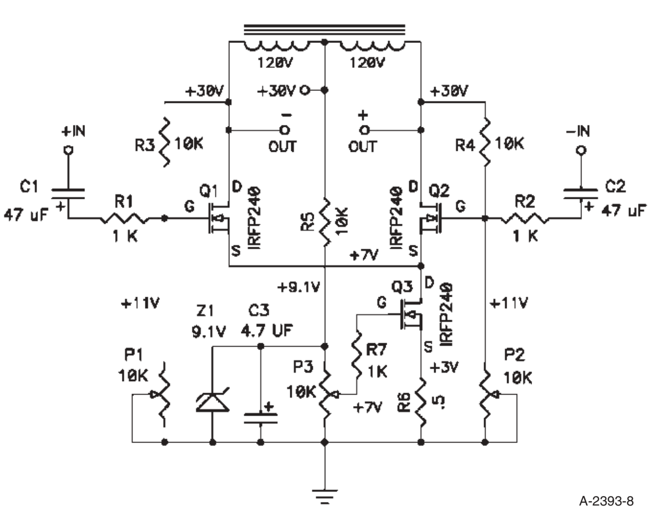

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FIGURE 8: ZV7-T.

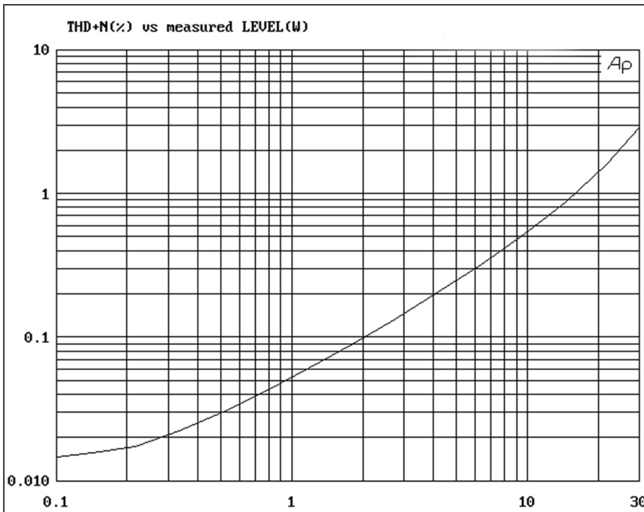

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FIGURE 10: Distortion with single-ended input.

Place C3 across this to remove the remaining supply and zener noise, and drive the gate of Q3 adjusted by P3. To further stabilize this circuit, place a nominal 0.5Ω power resistor R6 in series with the source of Q3.

The bias current through the circuit is adjusted by P3, and you can measure this current by the voltage across R6. In the case of *Fig. 1*, this has been set at 3V, which means that the circuit is drawing 6A total at a supply voltage of +30V, which is 180W. By the way, this 0.5Ω resistor will be dissipating about 20W. I suggest a 50W resistor mounted on the heatsink.

Why the lower supply voltage? Because the coupled inductors can swing much higher voltage than the supply—in an idealized case, they would peak at twice the supply.

I tried a number of transformer primaries and secondaries, and quickly found that the low voltage secondary windings didn't give me as much inductance as I needed, so I concentrated on using the primary windings as my load, which worked much better. I left the secondary windings open. The example of *Fig. 1* and the curves which follow

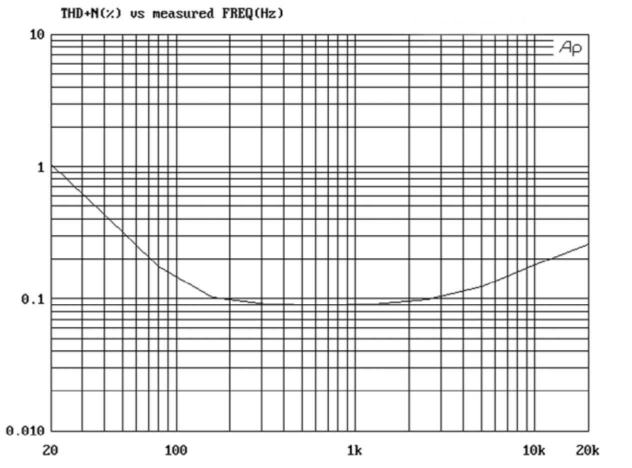

FIGURE 11: Distortion vs. frequency at 2W output with a balanced input.

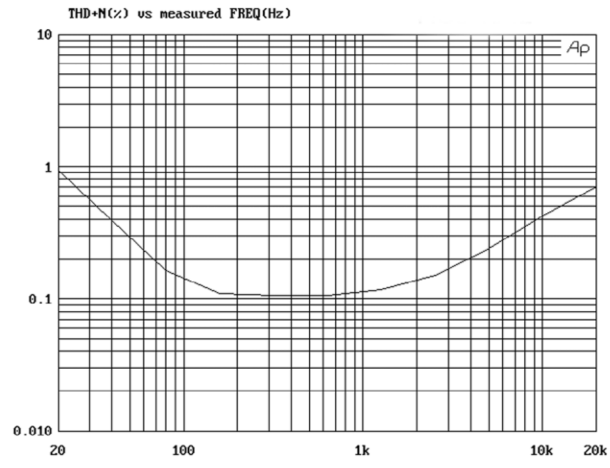

FIGURE 12: Distortion vs. frequency at 2W output with a single-ended input.

(*Figs. 9–14*) were taken with a 300 VA Plitron toroidal transformer. I also took some data with a similar, but much larger transformer. This example uses an off-the-shelf AC line power transformer, not at all optimized for audio work.

Of course, you could always go out and buy transformers actually designed for audio use, but how many of you have some nice piece of junk that you can use for free? What is surprising here is how well it works.

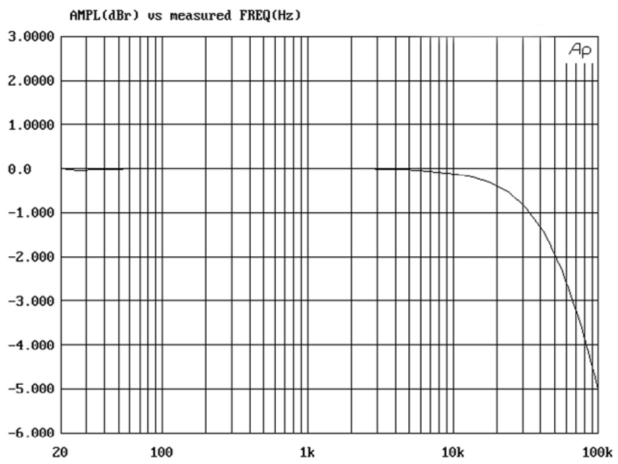

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FIGURE 13: Frequency response.

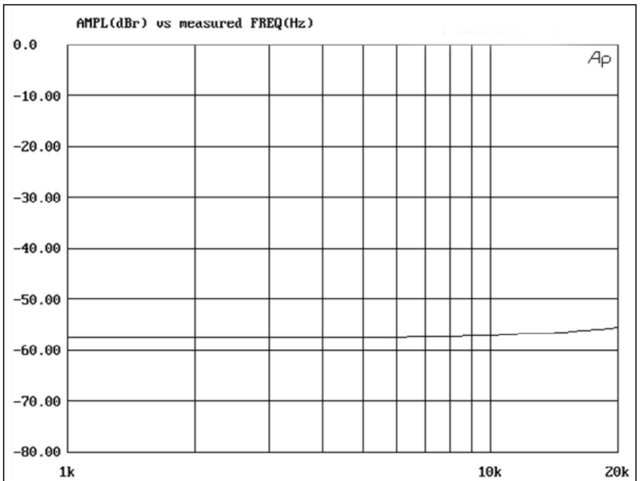

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FIGURE 14: Input common-mode rejection.

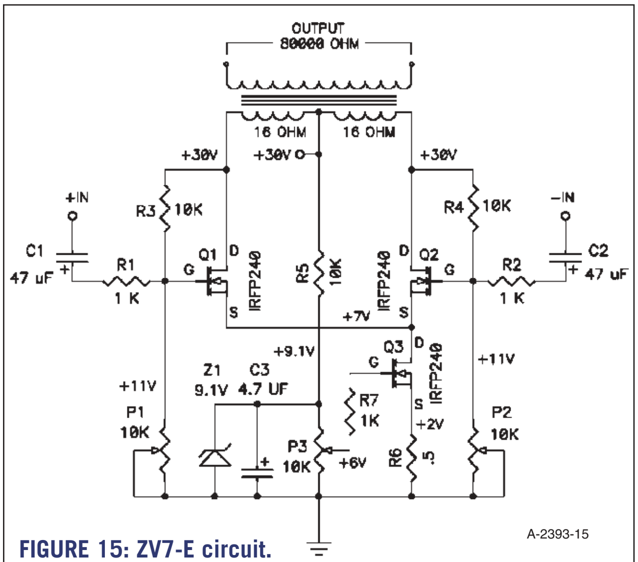

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FIGURE 15: ZV7-E circuit.

DISTORTION

When you are driving transformers in a balanced configuration like this, it is critical that you find the center operating point of the magnetic core in order to achieve the lowest distortion. This is more critical with toroidal-type transformers, which have tighter magnetic coupling. "EI"-type transformers are not as fussy, corresponding to a less efficient magnetic circuit. Either type of transformer will work, and either type still needs to be adjusted for lowest distortion.

Unfortunately, finding this point is a little trickier than you might think. I started out by simply adjusting P1 and P2, seeing to it that the DC potential across the windings was exactly the same—on the premise that this would be the magnetic center. Not so. Then I took great care to ensure that the currents were exactly equal, regardless of voltage. That didn't quite do it either.

Finally, I adjusted the balance for the lowest distortion, and then I adjusted it again later after the circuit had warmed up. It worked a lot better this way.

What does this mean to you? It means that I hope you have a distortion analyzer of some sort. It doesn't need to be a very good analyzer, but I don't recommend adjusting the circuit without one. If you can't buy a cheap used one, then build one. Try the IM analyzer recently featured in *audioXpress* (March '04, p. 8), or build a notch filter. Anything.

Figure 8 shows the circuit voltages that worked best for me, and *Fig. 9* shows the resulting distortion curve to 30W into 8Ω with a balanced input at 1kHz.

For a 60Hz AC power transformer not designed for audio, this was not shabby at all, and curious to see where it would fall apart, I pressed on with the same series of bench tests.

Figure 10 shows the same test, conducted with a single-ended input. As before, the results are nearly identical, except for slightly less noise and distortion with a balanced input.

Figure 11 shows the distortion versus frequency at 2W output with a balanced input. Here you start seeing some of the weakness of the transformer approach, with some core saturation beginning to occur at the lower frequencies. This sort of curve is typical of a lot of tube amplifiers—you could almost imagine this amplifier having that sort of sound.

Figure 12 shows the same test with a single-ended input. In both cases you note the increase in distortion expected at higher frequencies, but you see a new component at lower frequencies, reflecting the lower impedance of the coil and the distortion of the magnetic core.

The distortion increase at the bottom end is a real concern, given that *Fig. 12* is taken at only 2W output, and the distortion will dramatically increase with level. This is not the sort of transformer you would expect to deliver a dynamic bottom end with a lot of woofer control. At the same time, you don't expect that of any Zen—or Son-of-Zen-type circuit (at least not so far), and you usually use these amplifiers where the mid- and high-frequency characteristics are the most interesting. While I followed through with the two remaining tests, my eye was already straying toward a really big transformer, one that would surely give better bottom end.

Figure 13 shows the frequency response of the circuit, which was the same for both balanced and single-ended inputs, and you see that it is about 3dB down at 70kHz. In this regard it is not much different from the resistively loaded circuit. Clearly the magnetic core characteristics and winding capacitances of the AC line transformer are not producing problems at the higher frequencies.

Figure 14 shows the almost boringly superlative input common-mode rejection. So much for that. Right away I plugged in a big heavy 1500 VA toroidal transformer instead of the 300 VA documented in *Fig. 14*. The low-frequency distortion vanished by comparison, and for some unexpected reason the high-frequency distortion was also reduced (and I don't know why).

The other tests came out about the

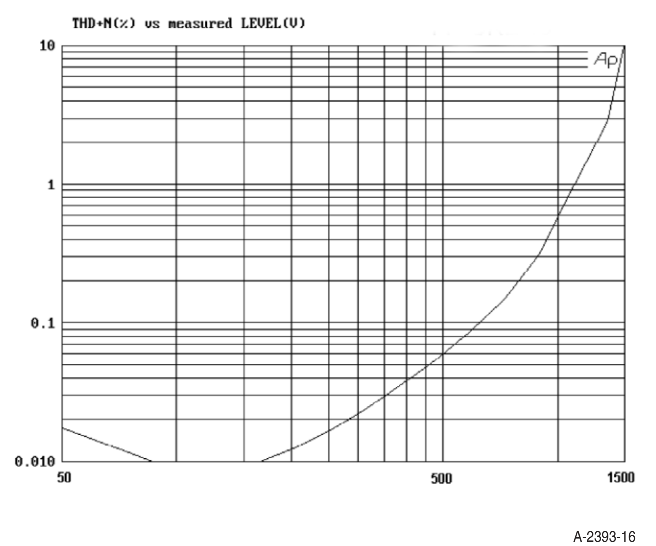

FIGURE 16: Distortion vs. output voltage at 1kHz.

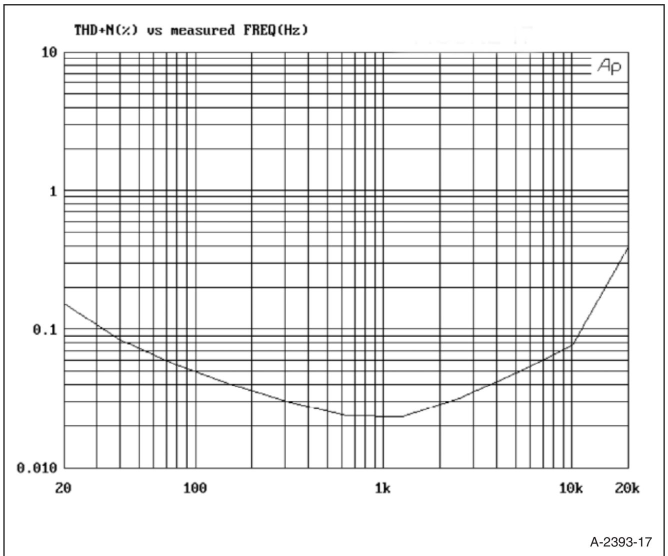

FIGURE 17: Distortion vs. frequency at 100V output.

same, and I did not see a significant loss of high-frequency response that I might have expected. The distortion figures immediately point toward the use of bigger transformers. No doubt your results may vary depending on what you try. Oh yeah, and the damping factor was a little lower at 2.25.

The biggest thing to be said is that the efficiency of the circuit climbed above 16%, at least a four-fold improvement, giving 30W output for a 180W input.

LISTENING TESTS

I listened to the amplifiers of *Fig. 1* and *Fig. 8* with a Wadia 16 driving the balanced inputs of the amplifiers into a pair of SEAS W17EX-002 5.5″ magnesium cone woofers with Vifa D25TG 1″ polymer tweeters mounted in 6′ transmission lines and single-pole crossovers. I listen to a variety of music, but because of the relative inefficiency of the speaker and low power of the amplifier, I stayed mostly with fairly simple solos: vocal, saxophone,

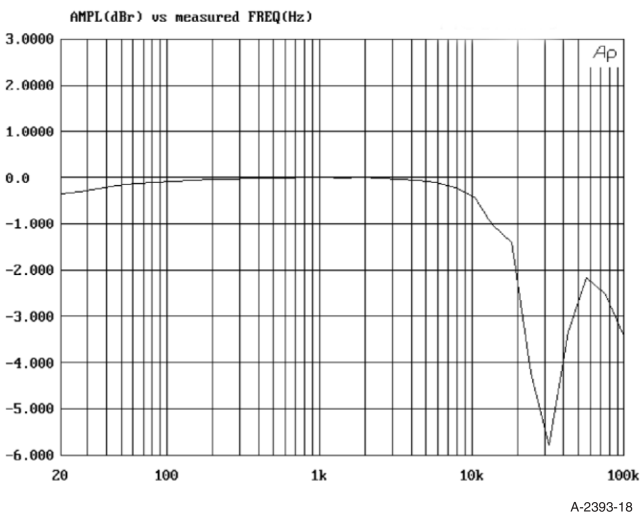

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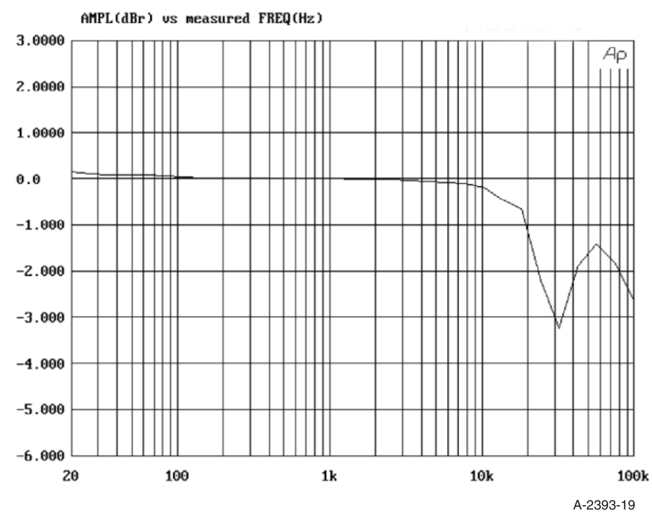
FIGURE 18: Frequency response unloaded.



A-2393-19

FIGURE 19: Frequency response with some resistive damping applied to the primary windings.

piano, violin. I like to hear these amps at their best, and big orchestral passages are not their strong point.

Basically, I found little to distinguish ZV7-R (*Fig. 1*) from ZV6. If you've already made a Son of Zen and given it the ZV6 feedback loop, then there's no reason to bother. If you are considering ZV6, then I recommend ZV7-R, which is a little simpler on the power supply and has greater efficiency. I also recommend it over ZV6 if you are using a single-ended input connection, as the performance is significantly improved, although I did not perform listening tests with just the single-ended input.

ZV7-T was a different story. I listened to the circuit of *Fig. 8*, and in spite of some of its measured shortcomings on the bottom end compared to ZV7-R, I found it more lively and musical. This is not to say that it was more accurate—it was simply more interesting and enjoyable for the time I have spent with it (which hasn't been very long).

WALKING ON THE WILD SIDE

I didn't try just AC power transformers. One of the samples that I hauled out of storage (think of the warehouse in "Raiders of the Lost Ark") was a Hammond 106940, the transformer that powered the legendary Dayton-Wright electrostatic loudspeakers immersed in sulfur hexaflouride. These monster transformers weigh about 50 lb and feature four 8Ω primaries and a single 80kΩ secondary, for a 100:1 step-up (unless you drive all four primaries in parallel, for a 200:1 step-up—a scary thought).

Well, who could resist? I ask you. The result is *Fig. 15*, configured for a 50:1 step-up and running the primaries in series for 16 + 16Ω.

The configuration is the same as ZV7-T, except that the output is taken off the secondary of the transformer for the purpose of driving the stators of an electrostatic loudspeaker. I am calling it ZV7-E. Unfortunately, I did not have an appropriate set of panels around, and I was unable to listen to this or even load it properly, but I did take the following set of curves from it.

Figure 16 shows the distortion versus output voltage at 1kHz.

Figure 17 shows the distortion versus frequency at 100V output.

Figure 18 shows the frequency response unloaded.

Figure 19 shows the frequency response with some resistive damping applied to the primary windings.

As I said, it was unfortunate that I was unable to get a listen, but I have applied modest amounts of feedback around these transformers before, and had good results. The 30kHz resonance seen in *Figs. 16–19* dropped down by a factor of 2 when they were originally loaded with the Dayton Wright panels, so you can imagine the curve shifting left about half an octave or more with the 50:1 step-up and loaded with a typical electrostatic panel.

We'll just have to save that for another time. . . ❖

A Dipole Midbass, Part 1

This author addresses the midbass problem in his system with this smart-looking (and -sounding) dipole speaker solution.

By Tom Perazella

In the January 2001 issue of *audioXpress*, the article "On Angels' Wings" presented information about the dipole mid/high frequency speakers I made based on the Bohlender-Graebener RD75 planar magnetic drivers (*Photo 1*). Those speakers were a great success and have provided many hours of truly wonderful music listening. The problem with any advance that you make in your sound system is that the new component usually points out the flaws in other parts of the system. The RD75s were no exception.

The lowest frequencies in my system were not a problem, being capably handled by eight 12″ woofers mounted in a 450ft^3 loft (see *Speaker Builder* 5/96, "True Bass"). But the midbass was being reproduced by a single 12″ woofer per channel. In most systems, having a 12″ woofer with over 12mm X_{max} covering the range of 60–250Hz would seem to be very adequate. However, with the huge amount of linear volume displacement available from both the sub at low frequencies and the RD75s at mid/high frequencies, it was apparent that the single 12″ driver could not keep up with volume displacement demands. In addition, the woofer was mounted in a sealed box, resulting in a radiation pattern quite unlike the RD75s.

PHOTO 2: The Peerless 831727 CC line 10″ driver.

To solve these problems, I decided on a dipole midbass solution (*Photo 1*). I had heard many stories about the magic of dipole bass and had also read articles about both the advantages and disadvantages of dipole drivers. For those wishing to learn more about dipole speakers, I have included a short list of references to a number of AES *Journal* articles and preprints. In addition to these references, additional works are mentioned in those papers.

PHOTO 3: Side view of a frame.

PHOTO 1: The author's completed system.

By the way, for those of you with a "monopole" woofer in a vented box, take special note of the paper by Geddes[2] describing the dipole nature of vented box designs. Most important, dipoles can control side radiation, an important factor in matching the RD75s.

Selecting the number and type of drivers to use was the first consideration. The calculated linear volume displacement of one of the 12″ drivers then in use was 95 in^3. I figured I would need about three times that volume displacement to match the capabilities of the subs and RD75s in their respective frequency ranges. There were several factors included in my decision, one being the need to limit the height of the final speaker to less than 6′ so the visual line from the RD75 baffle to an adjacent equipment cabinet could be maintained. Also, I wanted it to have sufficient volume displacement within that height limit, a relatively narrow width, and a reasonable price.

After looking at a number of drivers of different sizes and excursion capabilities, I decided on the 10″ Peerless model 831727 (*Photo 2*). This driver is handled by, among others, Madisound, who—as usual when I have placed an order—had the 12 pieces I needed in stock. Speaker building is a lot more fun when you have suppliers who not only carry a broad range of items but also carry sufficient stock to quickly fill your order when you need it.

The 831727 has an X_{max} of 9mm, uses a shading ring to minimize inductance problems with increasing frequency, and is reasonably priced. To achieve the desired volume displacement while maintaining the height limit, I decided to use six drivers per side. Looking at the math, six of the 10″ drivers per side would fall within the height requirements and provide about 270 in^3 of linear volume displacement. That is about three times the displacement of the single 12″ driver. Thinking about it, that's starting to get into the displacement region of a small block automobile V8 engine. Ah yes, that should do the trick nicely.

THE FOUNDATION

To mount the drivers, I decided against using a wood frame. That number of large drivers would not only be capable of generating substantial sound pressure levels, but also generating substantial vibration. To keep the mount as thin as possible and still provide the necessary rigidity, I decided to use a box section steel tubing frame. The only problem was that I had no way to fabricate one.

Looking at the cost of purchasing the welding and grinding equipment, the time it would take me to learn how to make proper welds (probably a lifetime), and the cost of failed attempts, I took the prudent route and located a shop in town that did custom welding and was willing to take on the job. I then needed to provide appropriate drawings, not just the hand-drawn sketches I use when making my own boxes.

The final form I decided on was to use a frame that looked much like a ladder, with two vertical members separated by horizontal braces. I would mount a driver in each of the squares formed by the vertical members and horizontal braces. Stability would be provided by two horizontal pieces running from the frame to the rear acting as feet, and two diagonal braces between the upright members and the horizontal pieces. A front view of the frame with dimensions is shown in *Fig. 1*, while you can see a side view in *Fig. 2* and a top view in *Fig. 3*.

In addition to the main frame, a piece of ¾″ angle was welded on to one vertical member in a mirror image arrangement on each frame. The purpose of that piece is to allow mounting of various sized baffles on one side of each frame in an asymmetrical arrangement, which turned out to be unnecessary. Please keep in mind when viewing the drawings that if you plan to build this frame, you can eliminate that angle iron piece. That will also make the construction of corner pieces easier.

The frames were welded, ground flat, primed, and painted by the shop. They also delivered them. The most amazing thing was that the total cost for all material and work including delivery was $320 for both. I really am glad I didn't try to do this part of the project myself. *Photo 3* shows a side view of a frame.

FRONT MOUNTING PANELS

To provide an easy method of mounting the drivers and also fill the front open

PHOTO 4: Saw setup for rabbet cut.

PHOTO 5: Driver drilling template in place.

space in the frame boxes, I cut a piece of ¾″ particleboard to fit the front of the frame. *Figure 4* shows the layout and dimensions of that piece.

I cut recesses to allow flush mounting of the drivers. What is not shown on the drawing is a rabbet cut around the edge of the plate that acts as a recess for mounting the grille to the finished speaker.

To make the rabbet, I originally started with my router. After trying to set up a guide and make a cut, it became apparent that this was not the easiest approach. I then decided to use a dado blade on my table saw. *Photo 4* shows how I clamped a scrap piece of wood to the rip fence as a guide. This allows the fence to actually touch the edge of the blade, allowing a cut right to the edge of the work piece.

Mounting a total of 12 drivers calls for drilling a lot of mounting holes. To simplify this procedure and make all the holes uniform in spacing and to make sure they are aligned the same way, I produced a drilling template to fit in the recesses of the front plate and with a mark to index the radial position of the holes. I drew a vertical line through the center of the front plate that was to be used for aligning the template.

Photo 5 shows the drilling template in place with the alignment mark on the template matching the index line through the center of the front plate. When the drivers were mounted, all the holes would be in alignment, adding a finished look to the project.

The front plate was to be mounted to the frame using carriage bolts, except for the one position that fell over the junction of the frame and diagonal brace, where a tapped hole in the frame received an Allen head cap screw. I marked the location of the holes in the front plate and used a Forstner bit to produce flat-bottomed recesses for the bolts. Then I drilled a through hole to accept the bolts (*Photo 6*).

Early on in the design process, I decided that I wanted to add mass and damping to the frame by pouring sand into the vertical frame tubes on the front. To contain the sand, I cut wood blocks the size of the ID of the tubing and later glued them into place at the bottom of the frame. Additional mass would come from cement poured into the cavities formed by the front frame sections and the front plate. To contain the cement so that it would not pour into the backs of the drivers, I cut rings of cardboard forms known by different names, including Sonotube®, from a single tube and hot-glued them into position at the back of each driver opening.

The challenge was cutting uniform width rings from a large, unwieldy tube. The answer was to make a slight modification to the rollout stands I use on my table saw and make a small jig from a piece of scrap wood to hold the rear of the tube as it was being cut. The rollout stands have a wide roller that allows

PHOTO 7: Saw setup to cut cement dams.

PHOTO 6: Drilling recesses for the mounting bolts.

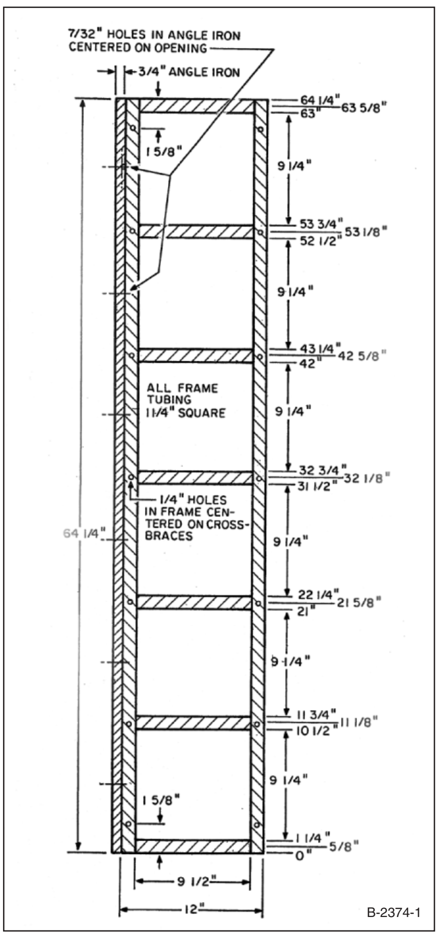


FIGURE 1: Frame drawing front view.

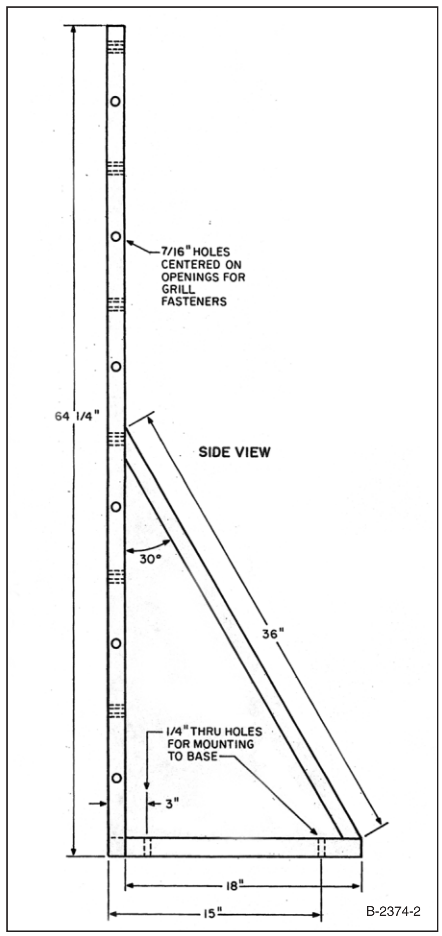


FIGURE 2: Frame drawing side view.

pieces being cut to roll off the table surface without falling to the floor.

Fortunately, the roller sections were bolted on to the stand sections. I removed and mounted them to pieces of scrap wood, which I clamped to the surface of the table saw, forming two support rollers that allowed the tube to be rotated smoothly while the cut was made. *Photo 7* shows the rollers and back support piece clamped to the table saw in preparation for cutting the tube.

I then placed the tube on the rollers and rotated it to make the cut using the rip fence to set the ring height. Even with the rollers and rear support jig, caution was needed when making the cuts as the sections are thin and tend to jam between the fence and saw. As with any cuts using a table saw, never stand directly behind the work as kickback from the blade can eject work pieces with considerable force. While making the dozen rings I needed, several pieces were sent flying across the shop. Fortunately, they are light and did no damage, although I would not want to get one in the face. The back of a front mounting plate with all the rings installed is shown in *Photo 8*.

Another consideration when mounting drivers is the amount of material available for the mounting screws. Since the drivers were recessed, the thickness of the front plate was reduced. To provide additional material for the screw to grip, I cut small wood blocks (*Photo 9*) from scrap stock and glued them to the back of each driver mounting pilot hole.

The front of the finished mounting plate with rabbet, driver recesses, driver pilot holes, and mounting holes is shown in *Photo 10*. The last step was to prime the front and sides of the plates and then paint those sides black.

PREPARING THE FRAMES

To allow for drilling tolerances when the mounting holes were drilled in the front plate, I used the front plate itself as a template to drill the mounting holes in the frame.

To mark the frame, I mounted the drill on the front plate with a drill support to make sure the bit was perpendicular to the frame. I started the drill and allowed the drill bit to lightly contact the frame just enough to make a mark (*Photo 11*).

After making the marks in the frame, I removed the plate and drilled the mounting holes. Except for the holes at the point where the diagonal braces meet the frame, all holes were clearance holes for the ¼ × 20 carriage bolts used and drilled through both sides of the square section box tubing. At the point where the brace meets the frame, I drilled and tapped holes for ¼ × 20 threads through the front part of the tubing only.

In my original design, one vertical edge was to be finished using a trim piece held in place by plastic fasteners used to hold speaker grilles in place. Parts Express offers these in several sizes, and I selected part number 260-367. There are two pieces to a set. The male piece (*Photo 12*) has a cylindrical section with flexible ribs to hold securely in a hole, and a round, split section that mates to the second piece, which is a round plastic cup.

I drilled the edge of the frame to receive the male part of the mounting pieces. In order to simplify the insertion of the pieces, I used a deep socket from a socket wrench set. I inserted the round end of the mounting piece into the end of the socket (*Photo 13*), placed hot glue around the ribs of the mounting piece, and then inserted the piece into the hole, lightly tapping on the back of the socket as necessary to seat

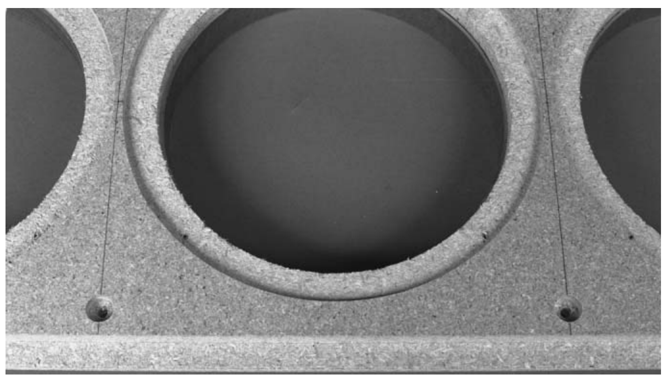


PHOTO 10: Front view of finished mounting plate.

PHOTO 8: Rings installed on the back of the front plate.

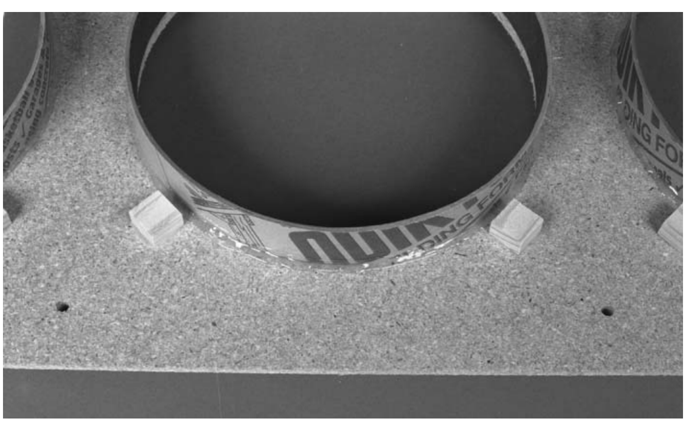


PHOTO 9: Mounting blocks installed.

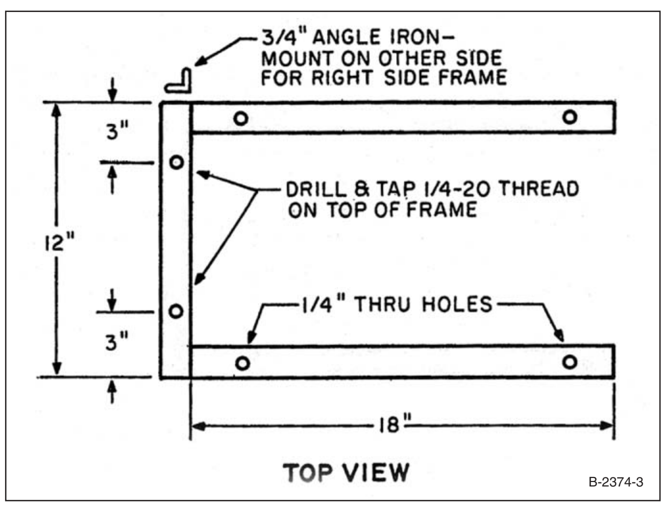


FIGURE 3: Frame drawing top view.

the mounting piece firmly into the hole. Removing the socket left a perfectly mounted piece in the hole (*Photo 14*).

I drilled the final holes in the frame: two ¼ × 20 tapped holes on the top cross member of the frame for fastening the decorative cap, and four clearance holes for ¼ × 20 mounting hardware for the base, two in each leg. After drilling all holes and tapping those requiring it, I deburred them and the frame, then cleaned off all shavings and cutting oil.

MOUNTING THE FRONT PLATES

Although bolts were the primary method used to fasten the front plates to the frames, I needed a glue/sealer to prevent the front plates from vibrating against the frames in areas between the bolts and to also provide a seal against leakage of the cement which was to be added for mass. I chose the heavy-duty version of Liquid Nails®.

I positioned the frame to accept the front plate by laying it on the rear of the base feet and supporting the top end on a box of suitable size so that the front was parallel to the ground (*Photo 15*). I positioned the front plate over the frame one last time to check the position of the mounting holes. Then I added Liquid Nails in a bead along the front of all frame members.

I positioned the front plate over the frame and then pressed it into place and immediately put the mounting bolts into place while it was still possible to move the plate before the glue set. I fastened the ¼ × 20 carriage bolts for all throughholes with ¼″ flat washers, ¼″ split lock washers, and ¼ × 20 nuts. For the tapped holes, I used ¼ × 20 Allen head cap screws with ¼″ flat washers and ¼″ split lock washers.

CEMENTING THE RELATIONSHIP

It was now time to add the mass to the front plates. In order to ensure proper adhesion of the cement to the various parts, therefore preventing separation and buzzing, I always use an acrylic latex-based liquid with the cement mix that is designed to be used when patching broken cement or applying a top

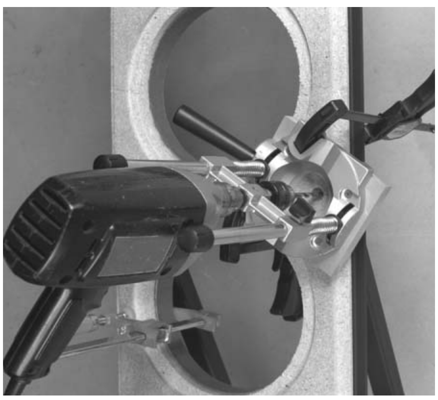


PHOTO 11: Using the front plate as a drilling template.

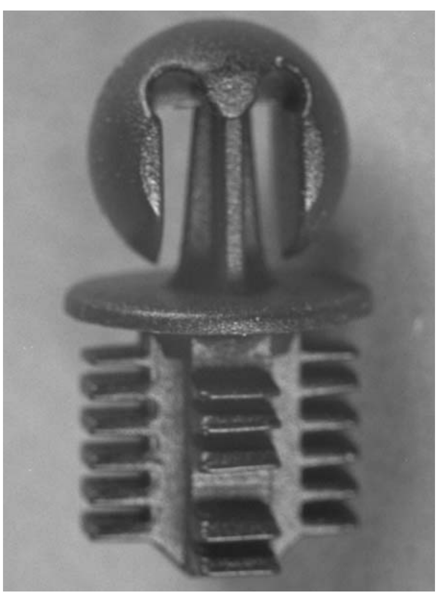


PHOTO 12: Male part of the grille mount.

finish coat. That liquid is sold in gallon containers and is mixed right along with the water into the dry cement mix.

Since this can be a messy process, and the cement/latex mixture can be difficult to remove if spilled, it's best to do this operation in an area where you can lay down a large plastic sheet under the frame. The cement used is a sand mix, not concrete, with no aggregate. Mix small batches at a time, as you do not want it to start hardening while you are trying to pour it into each section and smooth it out. Don't rush the process, as it is better to be careful in the first place rather than try to clean up a lot of mess.

As you pour into each section, smooth the surface and remove spillage. After the cement has had several days to cure, clean up the frames and re-spray them with black paint, including the mounting hardware.

TERMINAL BLOCKS

Since there would be six drivers in each speaker, there were several options on how to connect them. The various options require different numbers of terminals and therefore different terminal blocks. The impedance of each driver is 8Ω. You could use various combinations of series or parallel drivers to achieve different impedances. I have always avoided putting drivers in series, because the complex impedances of the drivers are between the amplifier and drivers when that happens. In certain cases, particularly around resonance, this can become a problem.

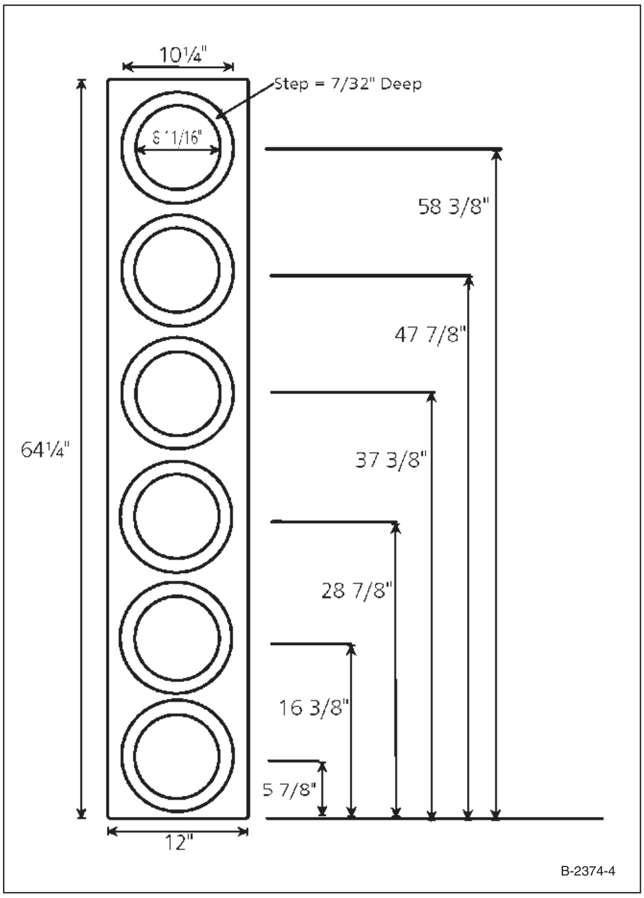


FIGURE 4: Speaker mounting plate drawing.

PHOTO 13: Grille mount installed in a socket.

Using a stroboscope, I have observed two drivers connected in series become out of phase with each other around resonance. That is, the cone motion of one driver would lead (or lag) the other cone as they went through their cycles. I don't know how audible this would be, but I have always put drivers in parallel to avoid this situation, and decided to do the same in this case.

Putting six 8Ω drivers in parallel is not a very easy load to drive. Instead, I decided to use three pairs of parallel drivers, resulting in three 4Ω loads. To drive them, I would use three stereo amplifiers.

In this case, my choice was the AudioSource AMP3. I have used this amplifier before with great results. Output into a 4Ω load with both channels driven is 244W at clipping. The price on this amp is also very reasonable, allowing the use of three amps for the same price as a single higher-powered stereo amp. I believe it has now been replaced by the AMP4 that has the same specs, but includes output meters.

This choice meant that the terminal block needed provisions for three pairs of binding posts. For all the exposed wood, I used walnut to match the baffles used with the RD75s. Those pieces included the terminal blocks, bases, end pieces, and top plates. For the binding posts, I turned to Vampire. I have successfully used both their line level and speaker level connectors extensively and find them to be of high quality and a very good value.

It is extremely frustrating to have bad electrical or mechanical connections constantly causing problems. Long ago, I decided to invest in good connectors and not worry about connection problems. The connector components from Vampire include long shafts which allow for mounting through thick cov-

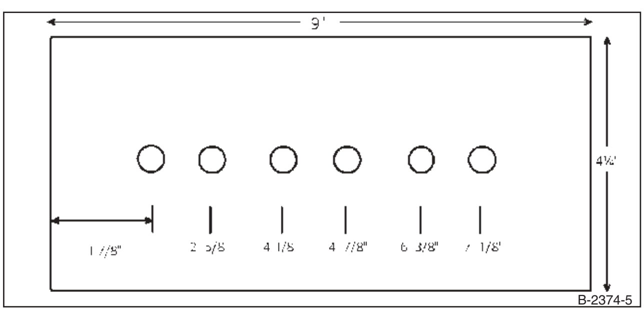


FIGURE 5: Terminal block drilling positions.

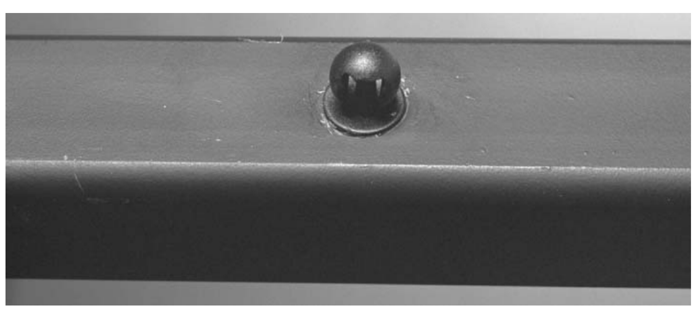


PHOTO 14: Grille mount in a frame.

ers. One of my biggest pet peeves—rotation of the post while tightening a connection—has been eliminated by the flats on the posts that fit into grooves in the mounting plate.

I made the mounting block from six pieces of ¾″ walnut stock, cut to size and glued into a box. Before assembling the pieces, I drilled the holes for the posts and lead-in wires. Drilling positions for the post holes in the box top are shown in *Fig. 5*. After the glue was set, I rounded the corners using a sander to produce a softer look. *Photo 16* shows the block after finishing and with the terminal posts installed.

SIDE MOLDINGS

There are various ways to produce rounded edges on a speaker project. One of my favorites has become the finished tubes called Hollowood supplied by Woodcraft. These tubes are multi-layered plywood pre-veneered with a choice of different hardwoods that are available in different diameters and lengths. In this case, I needed a half-round section. Taking one of these tubes in a 6′ length with a 2″ diameter and cutting it in half yielded two half-round sections that were already veneered. *Photo 17* shows the inside of a cut piece where the plies are visible.

Having this nice half-round section was great, but the question was how to mount it to the frame. The simplest approach was to fasten the section to a piece of ¾″ wood stock. That piece needed to have a specific shape to receive the half section on one side and fit to the frame on the other side while allowing room for the grille.

Before cutting the full-size pieces, I made a jig from a piece of scrap wood and used it to check the fit with the half-round section and also the frame.

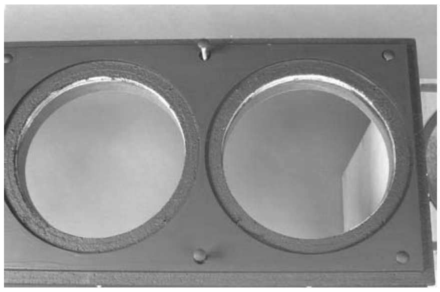


PHOTO 15: Final check of front plate fit.

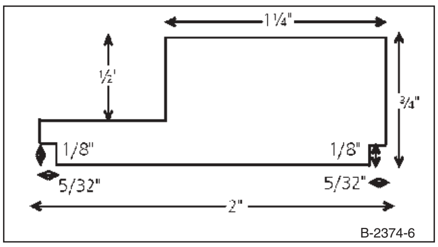


FIGURE 6: End support dimensions.

PHOTO 16: Connector block with posts installed.

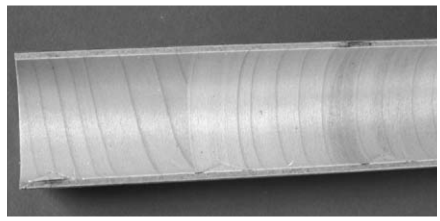


PHOTO 17: Inside structure of end tube cut in half.

Photo 18 shows the ultimate shape chosen for that jig. I then cut the full length supports, whose dimensions are shown in *Fig. 6*.

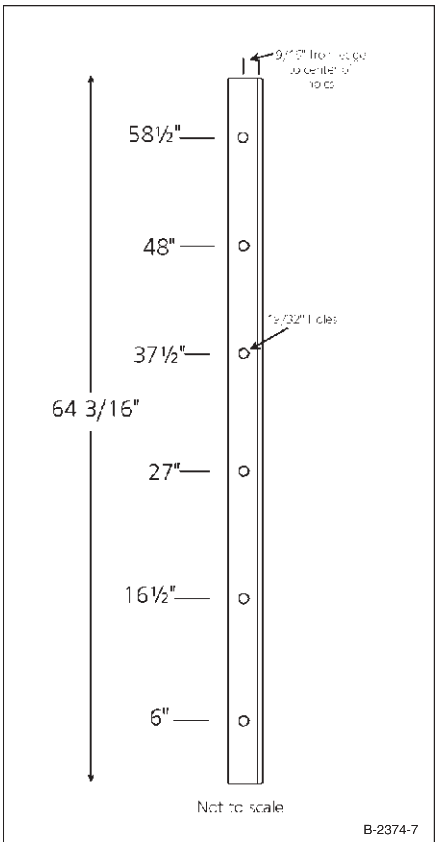


FIGURE 7: End support drilling positions.

PHOTO 18: Jig used to test end piece supports.

I drilled holes for receiving the female end of the plastic mounting fasteners into the support pieces, using a Forstner bit to allow flush mounting of the lip on the fastener and then another, smaller, Forstner bit to complete a flat bottomed hole (*Photo 19*). Hole positions are shown in *Fig. 7*. I then glued the fasteners into place. The final fit of the supports to the round sections is shown in *Photo 20*.

After sanding, I masked the supports along the two thin sections that would be glued to the round sections, then primed and painted them black. After the paint dried, I removed the masking tape and glued them to the round sections, making sure no glue seeped up on to the walnut veneer. I finished the veneer later.

TOP CAP AND BASE

The remaining two wood pieces per side are the decorative top cap and the base to which the frame is mounted. I made both from ¾″ walnut stock. For the cap, I cut a piece to size to cover the half-round end pieces and the front grille with about ½″ overlap. I rounded the edges using a router. I cut mounting holes and recess for the mounting hardware with a Forstner bit. *Figure 8* shows the dimensions of the top caps. *Photo 21* shows a top cap after sanding and finishing.

I made each base by butt-joining ¾″ walnut planks together to achieve the appropriate width. *Figure 9* shows the dimensions of a base including the mounting holes. I rounded the corners and edges with a router. *Photo 22*

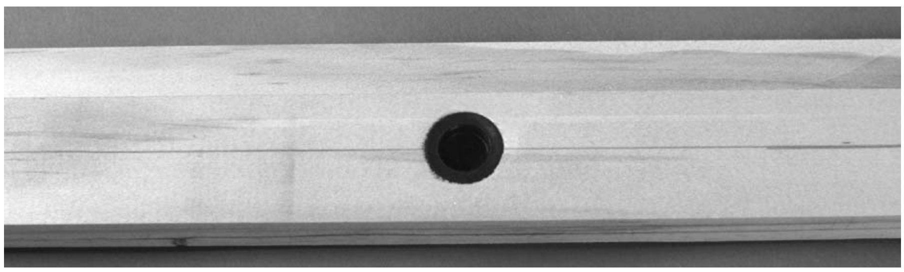


PHOTO 19: Female grille mount in end piece.

TABLE 1
MIDBASS COSTED BILL OF MATERIALS

Part #	Vendor	Item	Qty.	Unit cost	Total cost
1	JR Tech	One pair of frames	1	$320.00	$320.00
2 831727	Madisound	Peerless 10″ CC line drivers	12	$54.35	$652.20
3	Home Depot	One sheet of ¾″ particleboard	1	$19.00	$19.00
4	Menards	Gallon of Acryli bond liquid	1	$12.96	$12.96
5	Dundee Lumber	Raw ¾″ walnut planks-board feet	14	$3.78	$52.92
6 124552	Woodcraft	2″ Hollowood tubes per foot	12	$6.99	$83.88
7	Home Depot	1 × 6 × 6 select boards	3	$10.44	$31.32
8 BP1.5 Red	Vampire Wire	Red + black binding post set	6	$31.50	$189.00
9 260-367	Parts Express	Heavy Duty Grille Guides-pairs	12	$1.90	$22.80
10 080-525	Parts Express	½″ split loom tubing-feet	15	$0.12	$1.80
11 240-730	Parts Express	Speaker super toe spike set of 4	2	$12.90	$25.80
12 260-335	Parts Express	Grille cloth black 67″ wide-yards	2	$5.95	$11.90
13 091-332	Parts Express	Gold dual banana plug red	6	$4.80	$28.80
14 091-334	Parts Express	Gold dual banana plug black	6	$4.80	$28.80
15		Hardware, sand,cement, paint, wire, etc.	1	$75.00	$75.00
Total					$1,556.18

shows the topside of a base with the mounting holes drilled. I used spikes to help keep the base stable and also ease adjustment of the tilt of the speaker. In order to provide sufficient depth for the total travel of the spikes, I made mounting blocks out of scraps of the walnut planks. The bottom side of a base with the mounting blocks glued in place is shown in *Photo 23*.

FINISHING THE WALNUT PIECES

To finish the walnut pieces, I used my favorite technique. It is labor intensive, but results in a natural-looking luster that announces to anyone looking at it that this is real wood. To start with, as with any finishing method, sand all pieces with progressively finer paper grades until you believe you are finished. Then sand some more. Kidding aside, proper preparation of the surface is crucial to the final results.

After sanding, I vacuum the surface to remove any dust. This results in the grain being more prominent. Finally, I

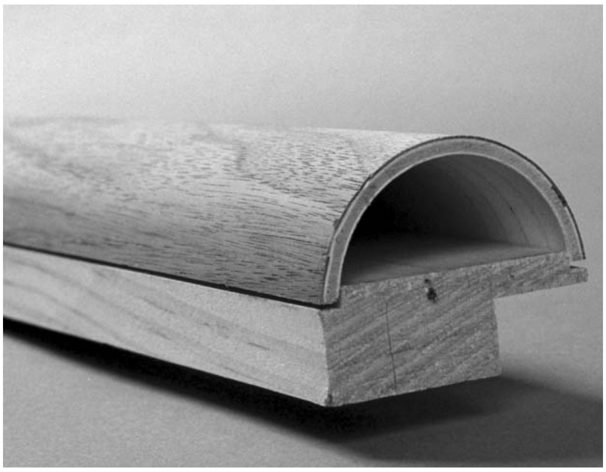


PHOTO 20: Fit of end piece to support.

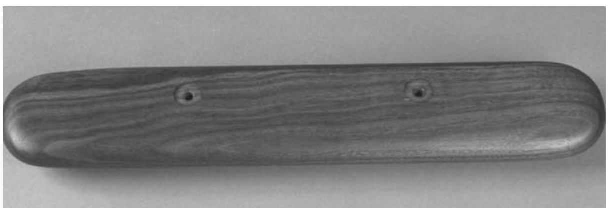


PHOTO 21: Top cap after sanding and finishing.

PHOTO 22: Top side of base with mounting holes.

PHOTO 23: Bottom of base with mounting block.

use a tack cloth just for good measure.

Since the color of the walnut is so nice, I generally use only oil with no stain. The one exception in this case was the half-round end pieces. The other pieces were slightly redder in color, so I stained them slightly to get a better match. I used Watco Danish Oil, an old standard that gives reasonable protection with an outstanding look. I would not use it for a dining room table or any item susceptible to spills, but for speakers it is great.

First, you saturate the wood with oil, let it stand for about 15 minutes, wipe off the excess, and let stand overnight. I then sand the wood and clean it again, and repeat the oil process. I generally do this process four times unless the wood needs more oil. After the second sanding, I apply the oil with #0000 steel wool instead of a rag and then do not sand any more.

Don’t forget the absolute rule when working with oil finishes: do not dispose of oily rags or steel wool in a trash container. Spontaneous combustion can occur, possibly burning down your house with your nice new speakers inside. Put any oily rags in a container filled with water before disposal.

After the oil has cured for several

PHOTO 24: Spike inserted into the base.

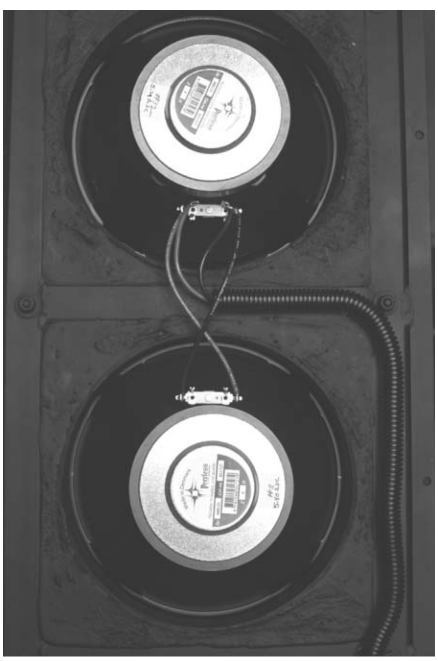


PHOTO 25: Wiring of one driver pair.

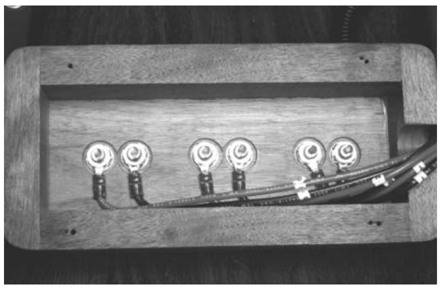


PHOTO 26: Wires installed on terminal posts.

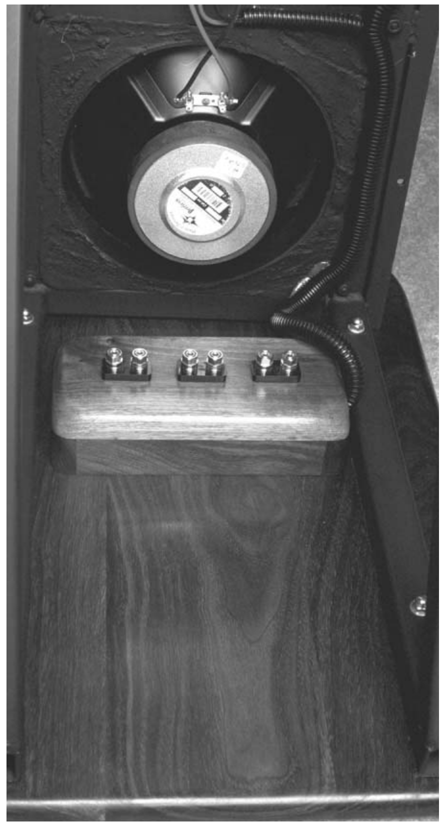


PHOTO 27: Terminal blocks fastened to the base.

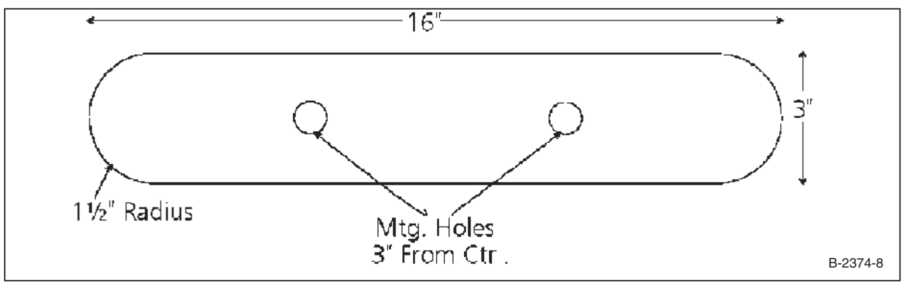


FIGURE 8: Top cap drawing.

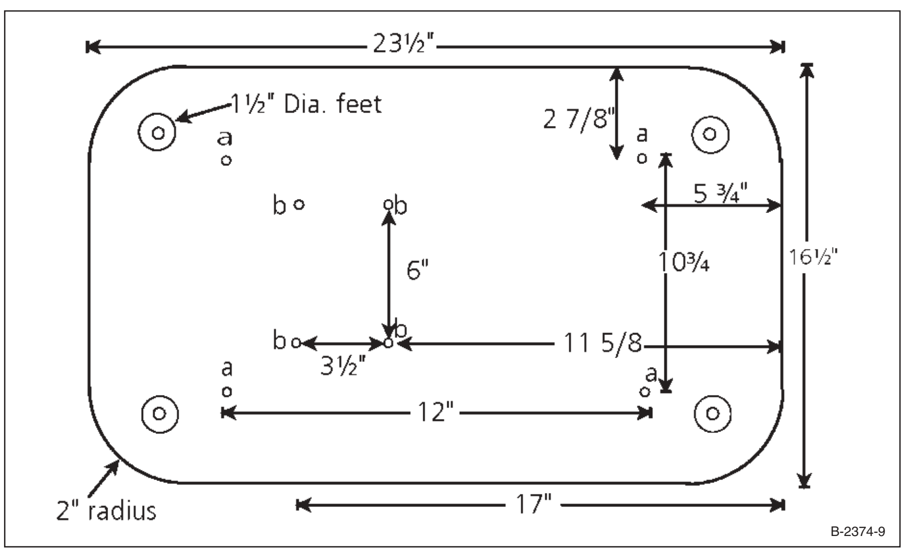


FIGURE 9: Base drawing bottom view.
a = ¼″ mtg bolt holes.
b = terminal block holes for #8 screws.

days, the final step is to add a coat or two of a good furniture wax. I have found Briwax, a mixture of carnauba and beeswax, to work well. The only future maintenance is to use Briwax about once every 6–12 months.

MOUNTING THE CAPS, BASES, AND DRIVERS

I then inserted the female mounts for the spikes into the mounting blocks on the bases. As with other pieces, I used Forstner bits to produce a three-stepped hole. The first step is a recess for flush-mounting of the lip of the mount. The second step is for the mount itself, and the third step provides sufficient clearance to allow complete retraction of the spike if needed. I then inserted the spikes into the mounts (*Photo 24*).

I mounted the caps with ¼ × 20 furniture bolts. I also mounted the bases with ¼ × 20 furniture bolts, but fastened them with flat washers, split lock washers, and acorn nuts.

For the drivers, I mounted pairs with their terminals facing each other. This minimized the distance between the terminals, making the parallel wiring easier. To mount the drivers, I used square drive screws from McFeely's. If you haven't tried square drive screws yet, do so on your next project. You won't go back to Phillips head screws again.

After mounting the drivers, I used #14 wire to connect the drivers to the terminal blocks. To keep the installation neat, I used split black plastic conduit, available from Parts Express. I hot-glued it to the frame with the split facing toward the inner side of the frame. *Photo 25* shows one pair of drivers with their facing orientation and wiring.

After mounting all the drivers, I brought the wiring down to the base and installed it in the terminal blocks. *Photo 26* shows the wires installed to the posts. Note the number tags on each wire, making identification of the driver pairs easier. I then fastened the terminal blocks to the bases (*Photo 27*). *Photo 28* shows a front view of the top of the completed speakers without grilles in place.

The finished size of the speakers blended nicely with the RD75 baffles and the equipment cabinet used to house all the electronics.

Next month, in Part 2, we'll conclude construction of this unit, including adding the grilles, and installation of the electronics. Then we'll test the system. ❖

PHOTO 28: Top front of completed speaker without grille.

SOURCES

McFeely's
1620 Wythe Road
Lynchburg, VA 24501
800-443-7937

Madisound Speaker Components
8608 University Green
Middleton, WI 53562
608-831-3433

Parts Express
725 Pleasant Valley Drive
Springboro, OH 45066
800-338-0531

Woodcraft
560 Airport Industrial Park
Parkersburg, WV 26102
800-225-1153

Vampire Wire
203 Flagship Drive
Lutz, FL 33549
813-948-2707

Etronics
216 Maspeth Ave.
Brooklyn, NY 11211
800-323-7669
etronics.com
Audiosource Amp3

MCM Electronics
650 Congress Park Drive
Centerville, OH 45459
800-543-4330
mcmelectronics.com
Audiosource Amp4

Musicians Friend
PO Box 4370
Medford, OR 97501
800-391-8762
musiciansfriend.com
Behringer control units DCX2496 and DEQ2496

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1. J. M. Kates, "Dipole Loudspeaker Response In Listening Rooms," JAES Vol. 50, pp. 363-374 (2002 May).
2. E. R. Geddes, "On Sound Radiation from Ported Enclosures," JAES Vol. 49, pp. 117-124 (2001 Mar.).
3. S. Linkwitz, "Investigations of Sound Quality Differences between Monopolar and Dipolar Woofers in Small Rooms," JAES *(Abstracts)* Vol. 46, p. 1032 (1998 Nov.), preprint 4786.
4. J. Salmi, "Dipole Source Placement in a Room," JAES *(Abstracts)* (1992 March), preprint 3327.
5. S. Linkwitz, "Why is Bass Reproduction from a Dipole Woofer in a Living Room More Accurate than from a Monopole Woofer," JAES *(letters to the Editor)*, Vol. 51, pp. 1062-1063 (2003 Nov.).
6. T. Salava, "Comments on 'Dipole Loudspeaker Response in Listening Rooms' and 'Perception of Reverberation Time in Small Listening Rooms,'" JAES, *(letters to the Editor)*, Vol. 51, pp. 248-250 (2003 Apr.).

35W Triode and 60W Ultralinear Control Amp

This author's latest in his series of high-quality amps is a low-cost, low-distortion stereo version featuring 6550 and 5687 tubes. **By Joseph Norwood Still**

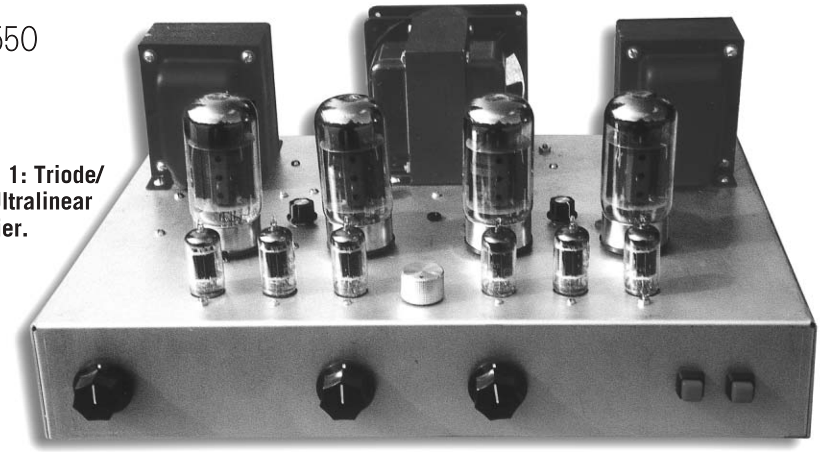

PHOTO 1: Triode/ 60W Ultralinear amplifier.

This completely self-contained stereo amplifier offers six inputs to accommodate a CD player, tuner, tape, satellite audio, phono amplifier, and so on (*Photo 1*). It uses push-pull 6550s to provide 35W output in triode mode or 60W output in ultralinear mode. This amplifier features high-perveance tubes in the line amplifier, driver, and inverter stages. These tubes provide circuits with a fast time/wide frequency response.

FEATURES

This amp is very stable and provides low distortion throughout the audio spectrum to its full output. The design offers all the best features of a vacuum tube amplifier that is required to satisfy the critical needs of audiophiles, for the low cost of $450. Features of the integrated amplifier include:

1. Readily available parts.
2. Reasonable weight, less than 30 lb.
3. Blower for forced-air cooling of the power transformer, under chassis components, and power output tubes.
4. Low-cost 5687 (Philips $3.80) and 6550 (Svetlana $104 matched Quad) vacuum tubes.
5. High power (35W triode or 60W UL, per channel).
6. Integrated power amplifier, including a line amplifier stage.
7. Conservative operating levels for all components.
8. Film and foil, polypropylene (Orange Drop®) capacitors.
9. Separate switches for heater and plate supplies to provide heater warm-up prior to applying plate voltage.

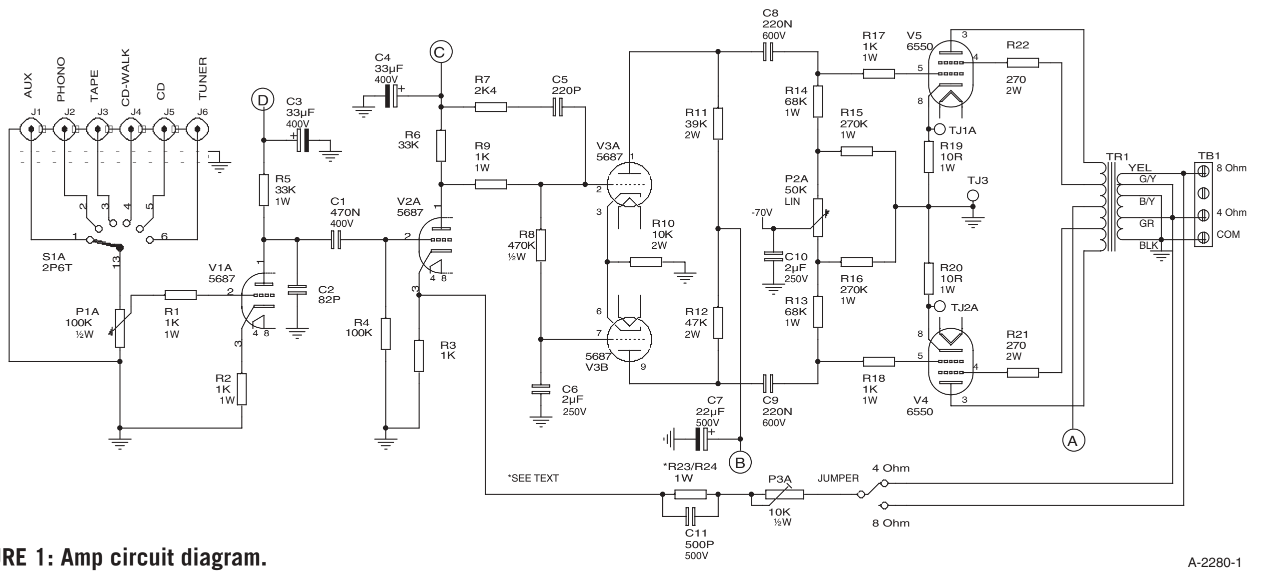

FIGURE 1: Amp circuit diagram.

10. Adjustable fixed bias controls and current test jacks for each 6550 output tube.
11. Adjustable inverse feedback control.
12. Separate right- and left-hand stereo volume controls.
13. Separate low cost transformers: filament ($25), bias ($5), and plate ($40).

35W TRIODE OUTPUT STAGE

The design features push-pull 6550s connected as triodes preceded by a 5687 duo-triode long-tailed phase inverter, a single section 5687 driver, and a single section 5687 line amplifier (*Fig. 1*). The advantages of triodes in the power output stage are improved frequency response, improved damping, and reduced distortion.

The amplifier with feedback applied requires 0.45V RMS drive signal at the input of the line amplifier for 35W output. A review of the tube data in *Table 1* reveals that the dissipation level is within the recommended dissipation ratings for these tubes. The 35W triode operation is obtained with a bias on the 6550s of −65V DC (approximately), providing a 45V RMS drive signal to the control grids of the 6550s. The distortion at 35W/1kHz is 0.3% and the frequency response at this power level is flat from 20Hz to 30kHz.

At 10W (normal room listening level) the frequency response is flat from 10Hz to 35kHz. The distortion at 35W/ 1kHz, no feedback applied, is 1.9%. The noise of the amplifier is 1.9mV with input open and volume control fully advanced.

Note: For triode mode you must connect a 270Ω metal oxide, 2W metal oxide

TABLE 1
TUBE DATA

6550 CLASS AB1 (PUSH-PULL)	TRIODE MODE	ULTRA-LINEAR MODE
Plate voltage	510/500V	510/485V
Grid voltage (nominal–see text)	−65V	−63V
Grid signal voltage, RMS	46V	46V
Zero signal plate current	120mA	120mA
Maximum signal plate current	200mA	230mA
Load resistance (plate-to-plate)	4.3k	4.3kΩ
Power output	35W	60W
Plate dissipation (per tube), no signal	31W	31W
Plate dissipation (per tube), max. signal	32.5W	26W
Plate input power	100W	112W
Power ratio efficiency	35%	53%
Harmonic distortion at 1kHz, no feedback	1.9%	2.3%

V1 5687 Eb1 90V, Ek1 3.7V (measured across 1kΩ resistor)
V2 5687 Eb1 75V, Ek1 3.0V (measured across 1kΩ resistor)
V3 5687 Eb1 310V, Eb2 308V, Ek1 and Ek2 85V (measured across 10kΩ resistor)

ABOUT THE AUTHOR

Joseph Norwood Still, retired from the Electronics Industry, is designing affordable high-quality audio amplifiers for the dedicated audiophile. This is a hobby he thoroughly enjoys and is especially rewarded with the many pleasant interchanges with those dedicated, resourceful audiophiles. Retirement is in the Town of Bel Air, MD.

He built this amplifier for his son Stephen Edward Still, Ph.D., Transportation Engineer and owner of Airline Planning Group, whose many accomplishments have made him very proud.

resistor from the screen grid to the plate.

60W ULTRALINEAR OUTPUT STAGE

The circuit diagram of the amplifier (*Fig. 1*) also features push-pull 6550s connected in an ultralinear configuration preceded by a 5687 duo-triode long-tailed phase inverter, a single section 5687 driver, and a single section 5687 line amplifier. The ultralinear operation shares some of the best features of a triode— primarily, improved damping, extended frequency response, and reduced distortion. It also has greater efficiency than a triode, nearly matching the efficiency of a pentode, and provides five times the damping of a pentode.

The amplifier with feedback applied requires 0.58V RMS drive signal at the input of the line amplifier for 60W output. A review of the tube data in *Table 1* reveals that the maximum signal dissipation level is within the recommended dissipation ratings for these tubes. I obtained the 60W ultralinear operation with a bias on the 6550s of –65V DC (approximately), providing a 45V RMS drive signal to the control grids of the 6550s. The distortion at 60W/1kHz is 0.22% and the frequency response at this power level is flat from 30Hz to 30kHz.

At 10W (normal room listening level) the frequency response is flat from 20Hz to 33kHz. The distortion at 60W/1kHz, no feedback applied, is 2.3%. The noise of the amplifier is 2.4mV, with input open and volume control fully advanced.

Note: When operating in the ultralinear mode the 270Ω, 2W metal oxide resistor must be connected from the screen of the 6550 and to the UL screen tap of the output transformer.

LINE AMPLIFIER AND DRIVER STAGE

The line amplifier (V1) uses a 5687 high-perveance, low-mu, single triode section and ensures a fast time, wide frequency response. The tube has a high cathode bias of 3.7V and provides considerable headroom for the input signals in relation to the bias voltage and ensures no clipping will occur during reproduction of music peaks. The distortion of the line amplifier is 0.22% at 3V RMS (0.46% at 8V RMS) connected to the driver stage.

The frequency response is flat from 10 to 20kHz. No feedback is used in this stage, other than the self-generated feedback of the unbypassed cathode resistor. Using no feedback in the line stage provides a lively, very realistic reproduction of the music presented to the first stage (driver) of the amplifier. (Note: C2 is an anti-ringing device.)

A single section 5687 (V2) is used for the first stage of the amplifier (*Fig. 1*). The distortion of the 5687 with 6V RMS output signal (no-feedback, not connected to the inverter) is less than 0.28%, and the frequency response is flat from 10Hz to 20kHz. The 3V DC cathode bias of V2 ensures no clipping of the audio signal will occur. The low-mu, low sensitivity of 5687 assures a stable feedback loop and lack of ringing in the amplifier with only minor circuit accommodations. All my power amplifier designs incorporate low-mu triodes and low value plate resistors for maximum bandwidth. Grid resistors for tubes V1 through V5 comply with maximum ratings specified in tube data sheets.

Caution: To avoid exceeding current rating of transformer T2, heater voltage is only applied to pins 4 and 8 of V1 and V2. Also, to avoid overcrowding of circuit components, use two tubes (V1 and V2) instead of a single tube.

INVERTER STAGE

The inverter (V3) employs a high-perveance 5687, connected in a long-tailed circuit configuration. The inverter has unequal output voltages due to the slightly higher gain of the grid-driven section. Balance of these sections is obtained by using a plate resistor of 39kΩ on the grid-driven section and 47kΩ on the cathode-driven side. The balance was maintained with five different 5687s, so this should provide a

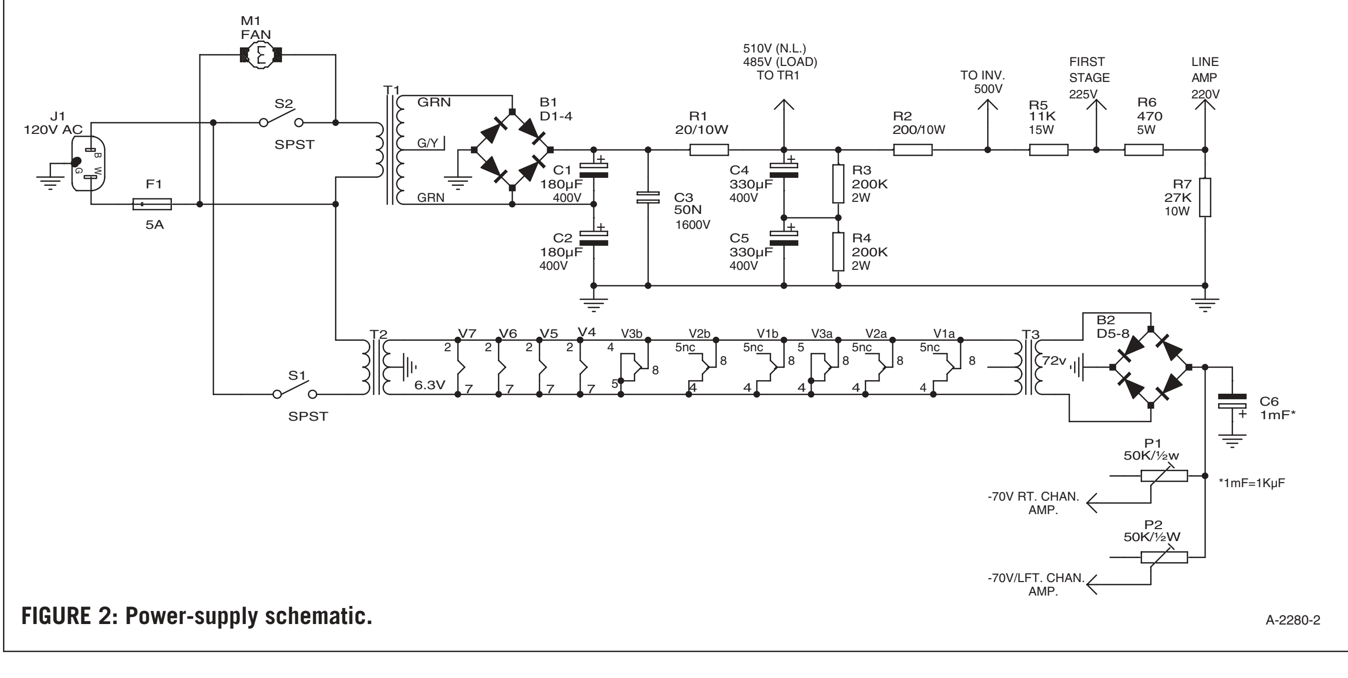

FIGURE 2: Power-supply schematic.

permanent fix. When power is applied to the inverter, make sure the voltage appearing at the cathodes of the 5687 (V3) is at least 8V more positive than the voltage appearing at the junction of R8 and R9 (*Fig. 1*).

Using the 5687 long-tailed phase inverter preceded by only a driver stage offered reduced phase shift and a stable feedback loop. Thus, only two stages are located within the feedback loop of the amplifier. I connected an anti-ringing R/C network (C5 and R7) to the signal grid of the inverter. The distortion of the inverter stage, measured on either side, (no external feedback) is less than 0.5% from 10Hz to 30kHz at 50V RMS output (measurements made with inverter not connected to grids of 6550 output tubes).

Allowing for the push-pull effect and resulting second harmonic cancellation, you can assume the total harmonic distortion for the inverter to be approximately 0.3%. The frequency response of the line amplifier, driver stage, and inverter is flat from 10Hz to 30kHz. The 45V RMS output of the inverter will drive the push-pull 6550s to their full-rated output of 35W, triode mode or 60W, ultralinear mode.

Of interest: Reviewing the tube manual and the characteristics of 5687 and 6SN7, you'll note that the 5687 possesses approximately the same characteristics as a paralleled 6SN7. It is important that you not exceed the design maximum 330 plate voltage of the 5687, and maximum voltage operation of 310V DC is recommended. There was only a small difference in the measured test results between the 6H30 and 5687, favoring the 6H30. The 6H30 high cost versus the $3.80 cost of the 5687 makes the 5687 the logical choice. Also of interest, it appears paralleling the 5687 would approximate the characteristics of the 6H30.

The tube manual electrical characteristics of the 6SN7 and 5687 are shown (the 6H30 mu, rp, and gm are calculated):

	6SN7	5687	6H30
Max. Plate Voltage	450	330	300
Plate Voltage	250	250	180
Grid Voltage	–8.0	–12.5	–15
Plate Current (mA)	9.0	12	10
Amplification Factor	20	16	15
Plate Resistance	7700	3000	1500
Transconductance	2600	5400	10000

Comment: It is my opinion that power amplifiers requiring a driver or inverter employ either 6SN7/6CG7, mu of 20, or high-perveance 5687, mu of 16. The best tubes for a line amplifier application are the 12B4A (mu of 6.5), 5687 (mu of 16), 6SN7 (mu of 20), and 6H30 (mu of 15). For phono preamplifiers, use low-noise 6922 (mu of 33) as the first stage. For the second and third stages, use tubes 6922/6DJ8/ ECC88 or high current version 6N1P. For sonic integrity, do not use high-mu triodes in hi-fi phono amplifier applications.

BIAS NETWORK

The bias network (*Fig. 2*) consists of transformer (T3), bridge-rectifier (D5-D8), and capacitor (C6). The 12V AC winding of transformer (T3) is connected to the 6V AC winding of transformer (T2). The 80V AC output from transformer (T3) is rectified by bridge-rectifier (D5-D8) and filtered by 1000µF capacitor, C6. The –72V DC output is tied to 50kΩ linear potentiometers (P1 and P2), and the output voltage at the arms of these potentiometers is connected to the bias resistors (P2A and P2B) of the right and left channel amplifiers (*Fig. 1*). These potentiometers are adjusted for a typical output of –62 to –68V DC—for correct operating bias of the 6550s or more precisely a 60mA operating current for each 6550.

Caution: Before applying plate voltage to the amplifier, make certain the grid circuit is wired properly and approximately –65V DC is present on the control grids of all four 6550s. Performing this procedure will prevent destruction of the 6550 output tubes.

OUTPUT STAGE (GENERAL INFORMATION)

The 6550s' push-pull output tubes operate class AB1 in 35W triode mode or 60W ultralinear mode, under conditions shown in *Table 1*.

The plate current of the 6550s is measured across 10Ω resistors in the legs of each cathode at test jacks TJ1 and TJ2 to TJ3 (*Fig. 1*). A 0.6V indication corresponds to a 60mA current reading. The carbon resistors connected to the control grids and the 2W metal oxide resistors connected to the screen grids of the 6550s are required to prevent oscillation of the output tubes. The 2W resistors must be the large types available from either Baynesville Electronics or NTE Electronics.

Most distributors stock small 2W resistors with a 250V rating; the larger resistors are rated for 500V operation. To ensure stable operation of the amplifier, you must connect the inverse feedback loop to the output taps in use.

For example, when using the 4Ω tap, connect resistor R24 (2400Ω) and capacitor C11 (500pF) to the 4Ω tap via P3. When using the 8Ω tap, connect resistor R23 (4700Ω) and capacitor C11 (500pF) via P3 to the 8Ω tap. If the amplifier requires the use of either 4 or 8Ω outputs, you must incorporate a switch in the amplifier.

If the amplifier is only used with 4 or 8Ω output, you may omit the switch. You must connect the secondary windings of the Hammond output transformer in a series configuration as shown in *Fig. 1*. If oscillation occurs when the amplifier is "turned on," reverse the primary plate leads of the output transformer.

AMPLIFIER POWER SUPPLY

For the schematic diagram of the power supply, see *Fig. 2*. The Hammond plate supply transformer (T1) has a secondary winding rated at 200V AC and 870mA and is available from Antique Electronics Supply for $40. The transformer is used in a full-wave bridge, voltage-doubler circuit; thus its output current capability is reduced to 435mA. This transformer, although small in size, runs cooler than the conventional Hammond transformer that is rated for full-wave operation at 800V AC C.T./465mA.

I used an 81 cfm (cubic feet per minute) fan to cool the plate transformer. Because of my experience with power transformers and their high heat levels, I suggest that all these transformers have a fan for cooling to dissipate the heat. You should locate the fan directly in front of the transformer and direct the airflow on the transformer. Mouser Electronics has a "quiet running" 4.72 square by 1″, 81 cfm fan for $14.

The bias supply (–72V DC) uses transformers T3 and a full-wave bridge rectifier. The potentiometers P1 and P2 are adjusted to set the bias to the 6550s. Final filtering is provided by capacitor C6, which limits the AC ripple to 0.016V AC. The filament transformer (T2) provides the 6.3V AC required to operate the four 6550 and six 5687 heaters.

The high voltage winding of transformer T1 "feeds" a full-wave, voltage-doubler rectifier (D1 through D4). The DC output of the supply is 510V (no load) and 500/485V DC with the amplifier producing 35W-T/60 W-U.L. output. Resistors R3 and R4 are voltage dividers for protection of the electrolytic capacitors C4 and C5. Capacitor C3 eliminates AC hash.

Capacitors C1 and C2 function as filters and voltage-doubler devices and capacitors C4 and C5 are the final filters of the supply. Resistors R1 and R2 provide isolation between the filter capacitors of the supply. Resistors R2/R5/R6 provide voltage reduction to the inverter, driver, and line amplifier stages. Resistor R7 is a bleeder resistor. The AC ripple of the 500V DC output of the power supply is 1.4V AC.

AMPLIFIER PERFORMANCE CRITERIA

The performance data of the amplifier is presented at its maximum operating levels. At 1W, from 30Hz to 15kHz, the distortion is less than 0.12% in the triode and ultralinear modes. The harmonic distortion data is presented for 5, 10, 20, 30, and 35W triode mode (*Table 2*) or for 10, 20, 30, 40, 60, and 70W ultralinear mode (*Table 3*). I made the amplifier distortion measurements using the 4Ω and 8Ω output taps, and the only

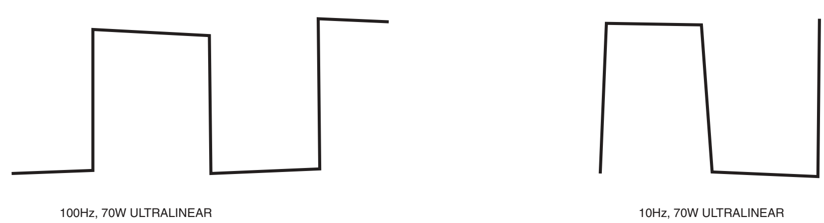

FIGURE 3: Square-wave oscillograms. A-2280-3

measurements shown are for the 8Ω taps, as the 4Ω tap measurements mimic the 8Ω readings.

The square-wave oscillograms are shown for the 35W-T/60(70)W-U.L. outputs of the amplifier (*Fig. 3*). The 100Hz and 10kHz squarewaves exhibit slight low- and high-frequency rolloff, while the 1kHz squarewave is reproduced almost perfectly. No high-frequency ringing occurred with the amplifier reproducing the 10kHz squarewave, even with a 0.1μF capacitor shunted across the transformer secondary—indicating good high-frequency stability. The amplifier is also stable at low frequencies. I made the 100Hz and 10kHz squarewave measurement with the squarewave signals “fed” to the input of the line amplifier. The squarewaves of the 35W triode and 60(70)W ultralinear amplifier are virtually identical.

Of interest: The frequency response of the triode mode amplifier at 35W out-

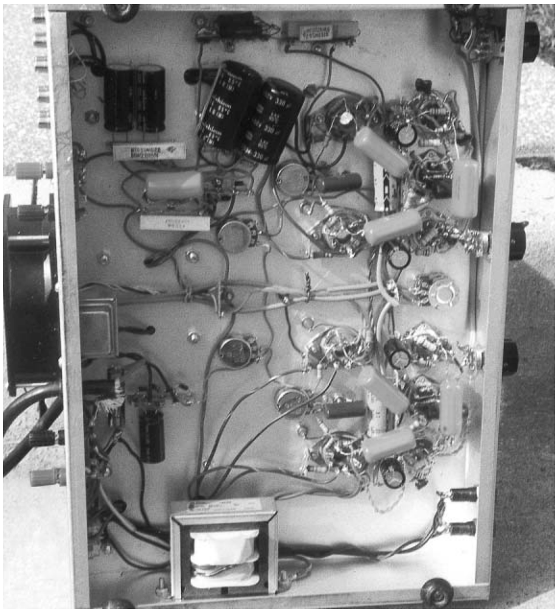

PHOTO 2: Underside of amp.

TABLE 2
TRIODE MODE TOTAL HARMONIC DISTORTION %

OUTPUT	5W	10W	20W	30W	35W
FREQUENCY					
30Hz	0.15	0.16	0.22	0.34	0.4
100Hz	0.14	0.15	0.2	0.31	0.32
1.0kHz	0.13	0.14	0.2	0.28	0.3
10kHz	0.17	0.30	0.44	0.54	0.56
15kHz	0.24	0.46	0.66	0.86	0.9

TABLE 3
ULTRALINEAR MODE TOTAL HARMONIC DISTORTION %

OUTPUT	10W	20W	30W	40W	60W	70W
FREQUENCY						
30Hz	0.12	0.14	0.2	0.32	0.64	0.75
100Hz	0.08	0.1	0.15	0.26	0.38	0.44
1.0k	0.05	0.07	0.1	0.15	0.22	0.24
10k	0.07	0.12	0.2	0.3	0.4	0.5
15k	0.08	0.14	0.26	0.36	0.56	0.84

put is flat from 20Hz to 30kHz; at 10W it is flat from 10Hz to 35kHz. The negative feedback of the triode amplifier is 18dB maximum.

The frequency response of the ultralinear amplifier at 60W output is flat from 30Hz to 30kHz; at 10W it is flat from 20Hz to 33kHz. The loop negative feedback of the ultralinear amplifier is 14dB maximum (the ultralinear connection provides approximately an additional 3dB of feedback). The noise of the amplifier in the 35W triode or 60W ultralinear modes, measured at the 4 or 8Ω taps with the input open and the volume control fully advanced, is 1.9/2.4mV. The performance specs speak for themselves; this is an amplifier that you can build for moderate cost and few construction problems.

HUM (NOISE) PROBLEMS

The amplifier is free of 60Hz hum and noise problems, so when you connect it to a loudspeaker absolute quiet is ensured. I recommend during the initial tryout that you only connect the amplifier and speaker. After you've determined that the system is quiet, connect the CD player to the amplifier. If the system is still quiet, connect the FM tuner to the system. Repeat this process of adding additional items.

If you add a phono preamplifier to the system, make sure the ground wire from the phono motor is connected to a ground post near the input of the phono preamplifier. Make sure all stereo audio input cables are standard shielded types. Also, make sure that all audio runs within the amplifier over 3″ use microphone shielded cable, grounded at input end. Do not use professional low impedance (600Ω) studio shielded audio cable.

Note: If you currently are using a solid-state power amplifier, be aware that it has a low impedance input and is much less prone to hum pickup than a high input impedance vacuum tube power amplifier. So, be prepared to eradicate any ground loops you may have in your system.

FORCED-AIR COOLING

The photos show an 81 cfm (noise 33dB) fan located directly behind the power transformer to cool the transformer. The air is routed to the right and left side of the transformer to cool the 6550 power output tubes. Also, a portion of the chassis at the lower end of the fan is notched out to provide under-chassis cooling.

I recommend that all power amplifiers use a fan to dissipate the residual heat build-up of the power transformer. Position the fan directly in front of the plate transformer.

Note: The following amplifiers should be modified to incorporate a fan for forced-air cooling:

GLASS AUDIO
40W Triode and 60W UL–Vol.10, No. 2, 1998
70W Triode–Vol. 10, No. 5, 1998
100W Triode–Vol. 12, No. 3, 2000
20W UL–Vol.12, No. 5, 2000
70W UL–*Glass Audio Projects*, 2002

CONSTRUCTION TIPS

I used "point-to-point" wiring in the amplifier (*Photo 2*). I do not recommend a

TEST EQUIPMENT USED:

Distortion Analyzer, H-P 331 A
Sine/Square Audio Generator, Heathkit 1C-5218
DMM, Radio Shack 22-168A
Oscilloscope, Proteck 6502

DISTRIBUTORS:
RS-Radio Shack

B.E.-Baynesville Electronics
1-410-823-0082

Radioshack.com
1-800-442-7221

A.E.S.-Antique Electronics Supply
6221 South Maple Ave.
Tempe, AZ 85283
602-820-5411

P.E.-Parts Express
1-800-338-0531

Al El–All Electronics
1-800-826-5432

Mouser
1-800-346-6873

AMPLIFIER PARTS LIST (DOUBLE-ORDER PARTS FOR STEREO, EXCEPT WHERE PRECEDED BY ASTERISK)

NOTE: ALL PARTS ARE AVAILABLE FROM RADIO SHACK (RS), RADIOSHACK.COM, OR BAYNESVILLE ELECTRONICS (B.E.) 410-823-0082

Component	Description	Part Number	Supplier
J1–J6	Female, phono jack, gold, chassis mount	274-852	RS
P1A–100K	audio taper, ½W, single section	900-7920	Radioshack.com
P2A–50K	linear taper, ½W, single section	900-7909	Radioshack.com
P3A–10K	linear taper, ½W, dual section	900-7939	Radioshack.com
*S1A	B-Rotary Switch, Double Section, 6 position	275-1386	Radioshack.com
R10–10K	2W, M.O.		B.E.
R11–39K	2W, M.O.(metal-oxide)		B.E.
R12–47K	2W, M.O.	900-0857	B.E.
R19, R20	10Ω, 1W, M.O.	900-0642	Radioshack.com
R21, R22	270Ω, 2W, M.O.		B.E.
*Cable, shielded, 6–conductor, Belden 9536		910-1605 (6′)	Radioshack.com
*Cable, shielded, microphone, Belden 9394		910-1650 (6′)	Radioshack.com

NOTE: ALL PARTS BELOW ARE AVAILABLE FROM ANTIQUE ELECTRONICS SUPPLY, 6221 SOUTH MAPLE AVE., TEMPE AZ 85283

Component	Description	Part Number
C1	0.47µF, 400V, polypropylene	C-PD47-400
C2	82pF, 500V Silver Mica	C-SM100
C5	220pF, 500V, Silver Mica	C-SM 220
C8, C9	0.22µF, 600V	C-PD22-600
C7	22µF, 500V	C-ET22-500
C11	500pF, 500V	C-SM 500
R1–3, R9, R17, R18	1.0K, 1W, C.F.(carbon film)	RB–1.0K
R5, R6	33kΩ, 1W, C.F.	RB–33K
R4	100K, 1W, C.F.	RB–100K
R7	2.4K, 1W, C.F.	RB–2.4K
R8	470K, 1W, C.F.	RB–470K
R13, R14	68K, 1W, C.F.	RB–68K
R15, R16	270K, 1W, C.F.	RB–270K
R23	4.7K, 1W, C.F.	RB–4.7K (only used with 8Ω speaker)
R24	2.4K, 1W, C.F.	RB–2.4K (only used with 4Ω speaker)
T1	Hammond, 60W, 4300Ω	

common ground bus with all components tied to this bus; instead, use an aluminum chassis to simplify the chassis ground connection process. Also use single ground lug terminals in addition to the center post of the 5-post terminal strip for all grounds. (When using a painted metal chassis, you must scrape the chassis to bare metal to make a ground connection.)

Most components are "tied" to the five-pin terminal strips; the center terminal is ground and components requiring a ground are tied to this ground post. All audio signal leads of 3″ or more must use a shielded microphone cable, grounded at input end. You may cut the primary and secondary windings of the transformer to shorten the plate leads and speaker leads. The power and audio output transformers are secured with ¼″ fasteners or similar large fasteners. The bias supply and the heater supply require the use of one terminal each.

Five terminal strips are required for the high voltage rectifier circuit. Four terminal strips are required for the 5687s. A terminal strip is located near the output transformer to accommodate the secondary leads. The heaters require no. 18 AWG wire which size "hook-up" wire is used throughout the amplifier.

Each side of the paralleled 6550 heaters have its heater wires returned to the 6.3V output winding of the transformer. A short ground path is provided for the ringing, grid, and cathode circuits of the 5687. The loop inverse feedback leads use shielded microphone cable. Use mounting "feet" on the bottom of the amplifier chassis to give good under-chassis "airflow." You must mount the 6550s' octal tube sockets so that the centers of the sockets are at least 3″ apart. For best placement of coupling capacitors (C1, C8, and C9) locate the inverter stage (V3) between the line amplifier (V1) and first stage amplifier (V2). The first stage amplifier is located adjacent to the feedback control (P3).

Note: The output transformer is rated for 60W; therefore, I classified the amplifier with a 60W rating, but as you can see from the distortion data the amplifier is capable of 70W output. I made the ultralinear amplifier "predistortion" measurements by adjusting the bias balance control for minimum distortion at 40Hz with 60W output. The simpler method of setting each output tube for precisely 60mA static plate current provided a distortion reading of 0.3% at 1kHz with 60W output. I also obtained the 0.3% distortion reading on both right- and left-channel power amplifiers. You would use the later method if a distortion meter and audio signal generator were not available. ❖

WARNING: Lethal voltages are present. Exercise extreme caution when constructing and testing the amplifier and never leave the amplifier upside down when children are present.

Component	Description	Part Number
	Ct., Sec. 4, 8, 16Ω	P–T1650N
V1-3		5687 (Philips, NOS)
V1S-V3S	9 Pin, subminiature	P–ST8–137R (¾″ D.) or tube socketP–ST9–511 (⅞″ D.)
V4S and V5S	Octal socket	P–ST8–209 MIP (1 3⁄16″ D.)
TJ1-TJ5	Insulated Tip Jack	S–H260/S–H261 (4 red, 1 black)
V4, V5		6550C, Svetlana (matched Quad)

NOTE: ALL PARTS BELOW ARE AVAILABLE FROM ALL ELECTRONICS, 1-800-826-5433.

Component	Description	Part Number
C6, C10	2.0μF, 200V, metalized polyester	RMC–220
C3, C4	33μF, 400V, radial electrolytic	33/400 VR

POWER SUPPLY PARTS LIST

Component	Description	Part Number	Supplier
M1	15V AC, 4.72inch^2 × 1″, 81 cfm, Noise 33dB, Fan	P.N. 670–0A125AP111TB	Mouser
T1	200V CT, 0.87A–Hammond	P–T167H200	A.E.S.
T2	6.3V CT, 10A–Hammond	P–T 166S6	A.E.S.
T3	12.6V CT, 0.450A	273–1365	RS
C1, C2	180μF, 400V	180/400 VR	ALEL
C3	0.05μF	1600V–C–SD05–1600	A.E.S.
C4, C5	330μF, 400V	EC–3341	ALEL
C6	1000μF, 100V	1000/100VR	ALEL
D1-D8	2.5A	1000 P.I.V. (order 10), 900–2875	Radioshack.com
R1	20Ω, 10W, W.W.	900–1056	Radioshack.com
R3, R4	200K, 1W, metal-oxide	900–0754	Radioshack.com
R5	11K, 15W, W.W.	900–1241	Radioshack.com
R6	470, 5W, W.W.	900–0960	Radioshack.com
R7	27K, 10W, W.W.	900–1131	Radioshack.com
P1, P2	50K, ½W, linear potentiometer	900–7909	Radioshack.com
FH-1	Fuse Holder, ½″, 20A, 250V	P.E.–071–510	
F-1	Fuse 3AG, 5A, Slow-Blow, Time Delay for inductive surges	P.E. 070–343	
S1, S2	Switch, S.P.S.T, 3A, 115V	275–617	RS
AC Cord	6′, 18 AWG, 1250W	910–1730	Radioshack.com
Terminal Strip	5 lug.	274–688 (4-packs)	RS
Chassis	Aluminum, 17 × 10 × 3	P–H1444–32	A.E.S.
Hook-up Wire	3 Spools, Black, Red, Green	#18 278–1223	RS
Ring Tongues		64–3040	RS
Solder-Rosin Core		64–006	RS
Cable Clamps		64–3028	RS

KT88 Hybrid PP Stereo Power Amp

This noted Japanese designer offers his latest tube-based high-output power amp. **By Satoru Kobayashi**

PHOTO 1: KT88 tube.

I have recently upgraded my speaker system from JBL to B&W, which as you may know, is well known as a linear phase speaker and high-power durable driver. I have driven this speaker with an SV300B single-ended amplifier at only 10W output, though the amplifier could not drive sufficiently due to a low efficiency of 92dB compared to the JBL S3100 system's 96dB. At the peak sound level of any kind of music, the B&W speakers driven by SV300B amplifiers emitted a lot of distortion, giving me a headache. Thus, I decided to build a KT88-based higher output amplifier.

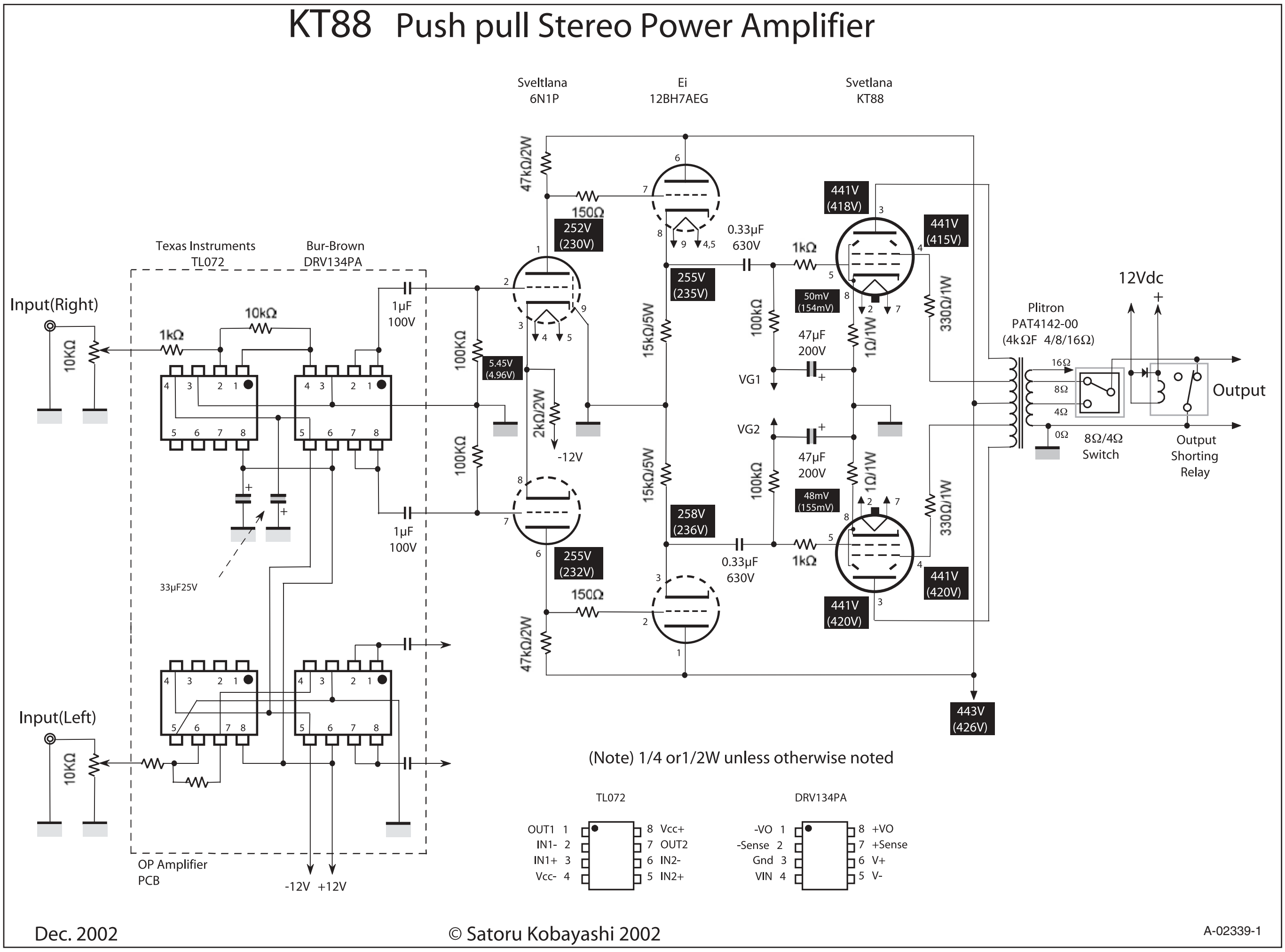

FIGURE 1: Circuit diagram.

I am quite satisfied with the sound and performance of this amplifier. It showed an ultra-wide frequency response with the finest linearity, so I am now very confident that this amplifier could handle even SACD and DVD audio signals, reproducing 96kHz sampling as well as conventional CD sound.

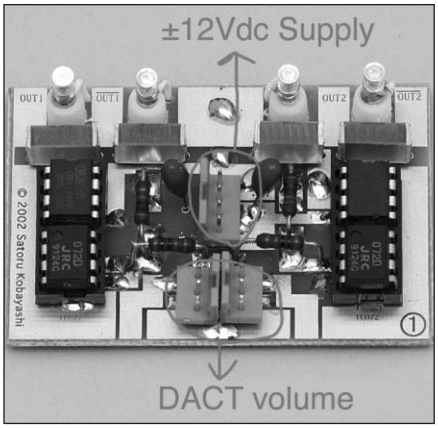

PHOTO 2: Phase inverter board assembly.

ABOUT THE AUTHOR

Satoru Kobayashi is from Tokyo, Japan. He has been interested in audio and in ham radio since he was in his teens. After majoring in EE in Tokyo, he joined the semiconductor industry, designing DRAM chips for a living, although he now works in the technical and marketing area of semiconductor packaging industry. His debut as a writer came in the early '80s in the form of an article about ham radio for CQ *magazine. Now he periodically writes on the subject of audio for a few different magazines. Author's e-mail: fwt34641@yahoo.co.jp.*

CIRCUIT OVERVIEW

The amplifier features a hybrid voltage driver circuit, consisting of an IC phase inverter, a differential valve amplifier, and a cathode follower that demonstrates an ultra-high linearity and a wide frequency response with low distortion without negative feedback (NFB) (*Fig. 1*). Also, the circuit is completely symmetric, so, theoretically—and even

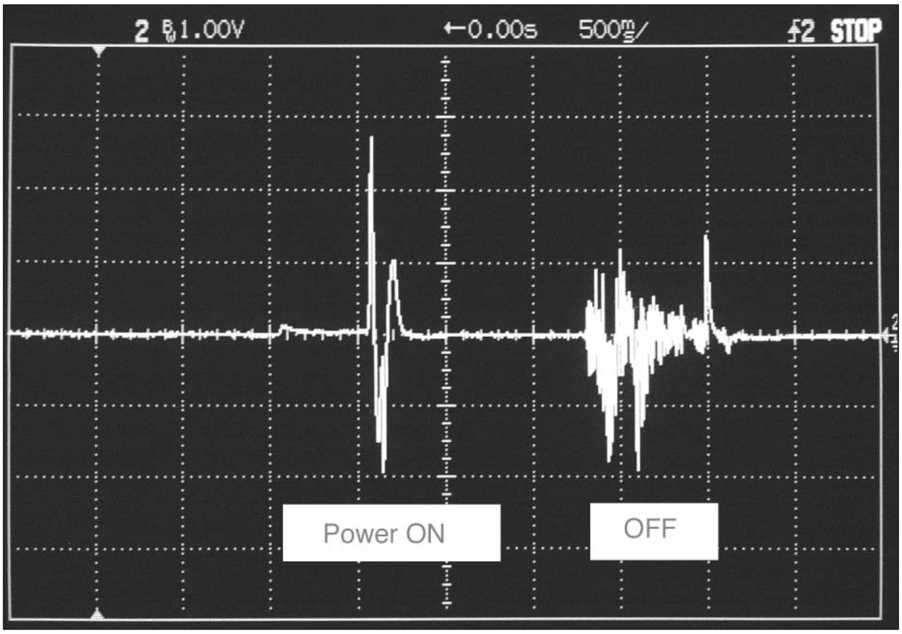

PHOTO 3: Noise voltage at speaker terminal (unprotected).

practically—no AC balancing is needed.

The measured performance shows a low distortion (<2~3%), a high linearity and a high power output (≈70W), and an ultra-wide bandwidth (≈100kHz), owing to the collaboration of the following circuits and Plitron toroidal output transformer.

- Phase Inverter

The first stage uses a TL072 (MOSFET high impedance input, low noise operational amplifier) and a DRV134PA (balanced output line driver), providing a 10× gain and a couple of complementary output signals.

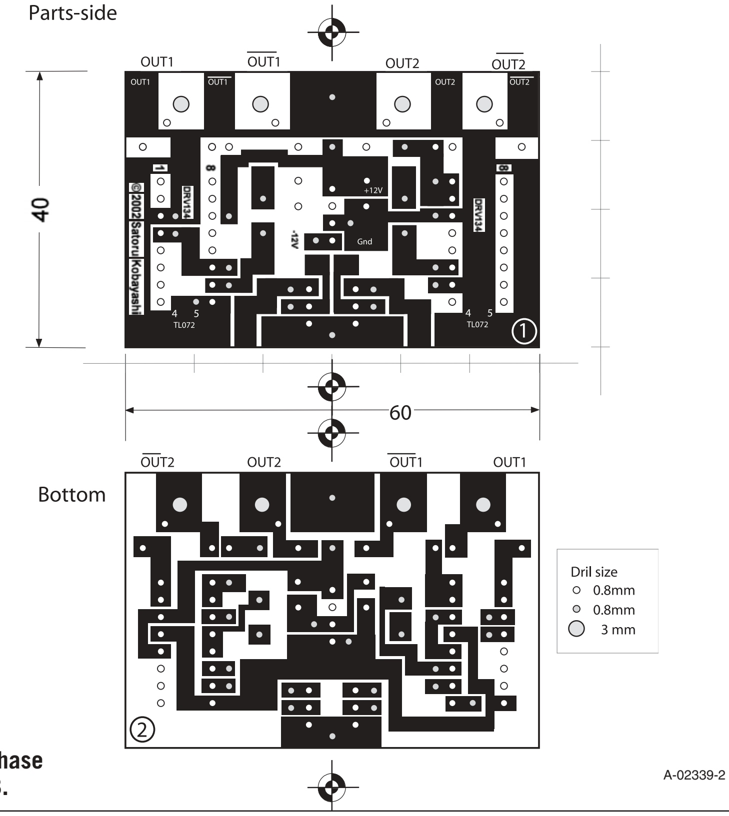

FIGURE 2: Phase inverter PCB.

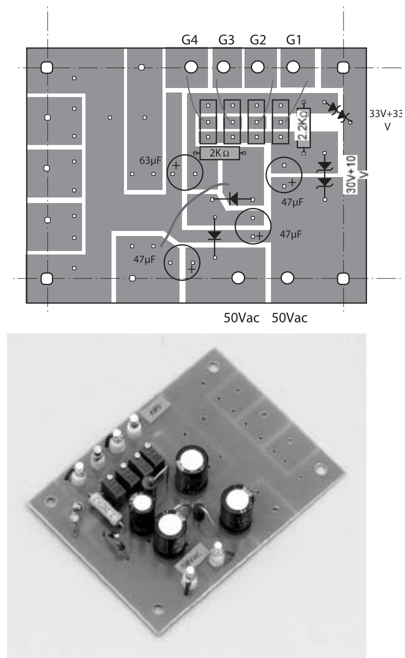

FIGURE 4: C– power-supply PCB.

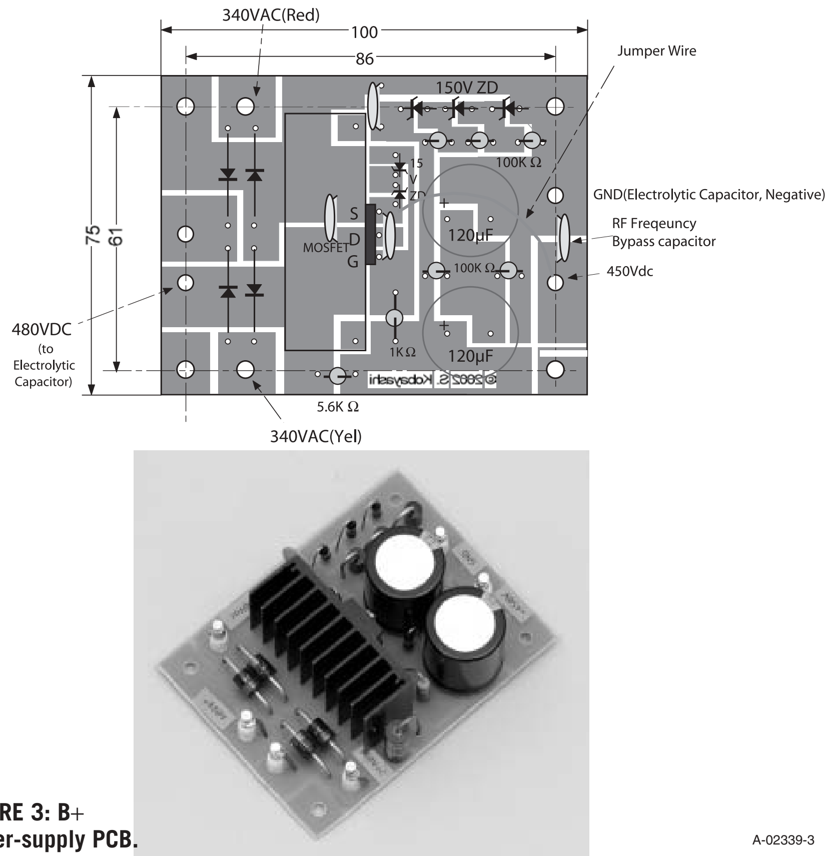

FIGURE 3: B+ power-supply PCB.

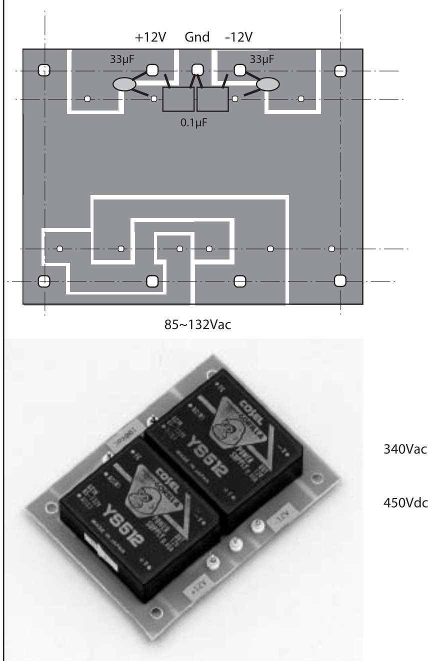

FIGURE 5: ±12V power-supply.

• Differential Amplifier

I believe a differential amplifier is a good choice to amplify the complementary signal out of the previous stage to drive a push-pull KT88 tube. The Svetlana 6N1P, which is one of my favorite valves, provides a wide linearity characteristic and low noise, with a 30× gain. The differential amplifier with this tube generates at least a 120V pp signal to drive KT88 tubes, followed by an IC phase inverter, while the maximum output voltage will be 250V pp or up to 300V pp, showing the high linearity and output.

The 6N1P differential amplifier needs a couple of DC supplies, which are +450V and −12V, respectively, to enhance linearity and noise margin. Owing to this configuration, any AC balancing procedure—usually a headache for beginners at the adjustment stage—was totally eliminated.

• Cathode Follower

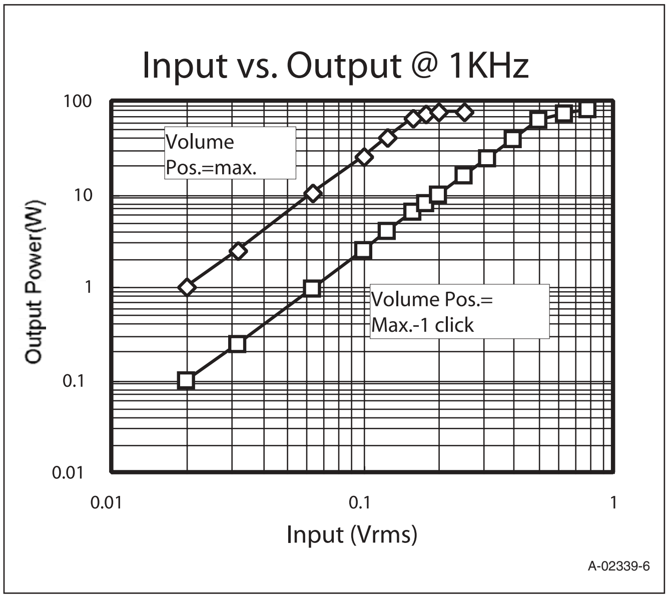

FIGURE 6: Input-output characteristic.

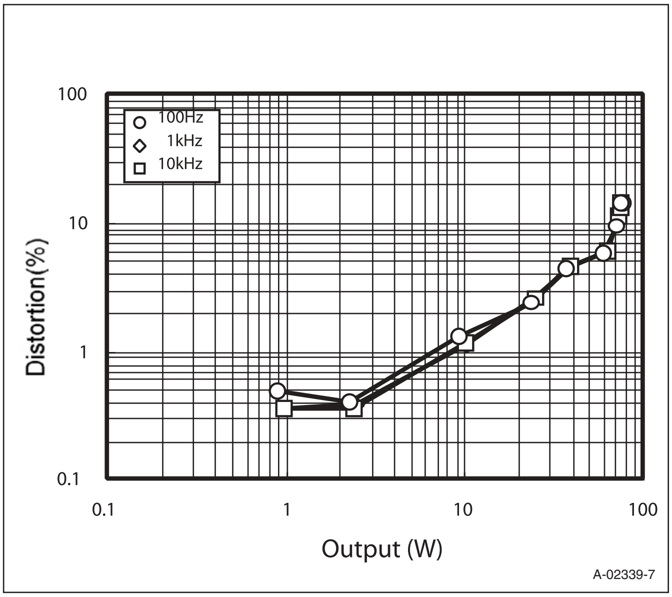

FIGURE 7: Distortion.

The circuit employs a 12BH7A (6FQ7 could be an alternative, though it needs a heater wiring alteration), forming a cathode follower, with the output impedance of approximately 100W through 300W, and drives KT88 grids via a 0.33μF film capacitor. The circuit features an ultra-wide frequency bandwidth (>400kHz). Actually, I have evaluated several tubes for this purpose out of my parts box, such as the 12AU7, 6FQ7, and 12BH7A. The 12BH7A showed the best performance in terms of the linearity and distortion.

- Power Amplifier

The final stage employs Svetlana KT88 tubes with a Plitron toroidal transformer, ultralinearly connected (*Photo 1*). A 1Ω resistor inserted at a KT88 cathode pin and the ground monitors an idling current (50mA) to establish an operating condition.

- Power Supply

The power supply block provides B+ supply (+450V), C– supply (–60V), and ±12V supply separately, mounted over a PCB for the convenience of assembly and maintenance, which is my favorite assembly criterion.

- B+ Power Supply

The B+ power supply consists of four bridge-connected fast recovery diodes and a 270μF 550V electrolytic capacitor specially developed by Nichikon in Japan, and a MOSFET ripple filter with a zener diode stabilized feature. This circuit perfectly eliminates a conventional choke coil, since a ripple rejection rate is comparable with—or better than—a choke coil. A 550V electrolytic capacitor is hardly available anywhere, so an alternative component is a regular 500V capacitor with a bleeder resistor such as 75kΩ 5W connected in parallel. This may suppress an overshoot voltage beyond 500V when you turn the power switch on.

- C– Power Supply

Since Plitron power transformer #854710 provides only 50V AC wiring, you need a voltage doubler to generate –40 to ~–65V DC negative grid bias for KT88 grids. Several zener diodes with a 3 to 5mA bias current stabilize a grid bias. A 20–turn potentiometer implemented could adjust a bias voltage by a few mV–resolution per turn.

- ±12V Power Supply

A ±12V DC power supply for IC phase inverter comes from a couple of switching regulators mounted neatly on the PCB, since a regulator is really compact and fits in the chassis.

MAJOR COMPONENTS

To achieve a professional look, I paid a lot of attention to the parts selected for this project.

- Custom-made chassis

This stainless-steel chassis has been my favorite style since 1998 (for chassis drawings, visit www.audioXpress.com). I ordered it from EL Audio, a chassis manufacturer, in Isehara–shi, Japan. If you are interested, you might get in touch with them via e-mail or fax. They take orders even from the US. The chassis itself adds a professional look to the project.

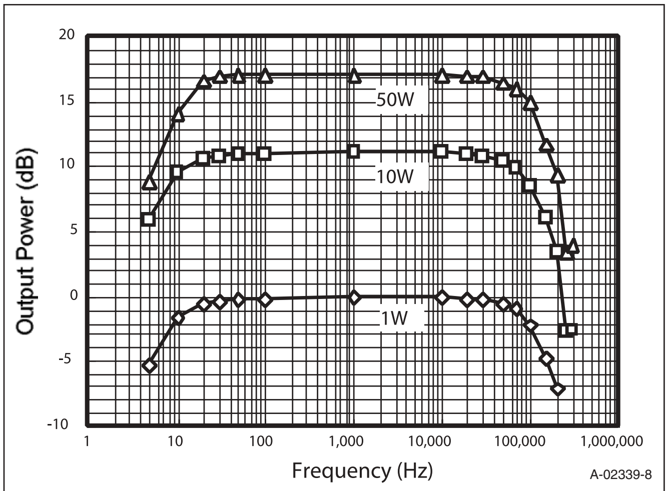

FIGURE 8: Frequency response.

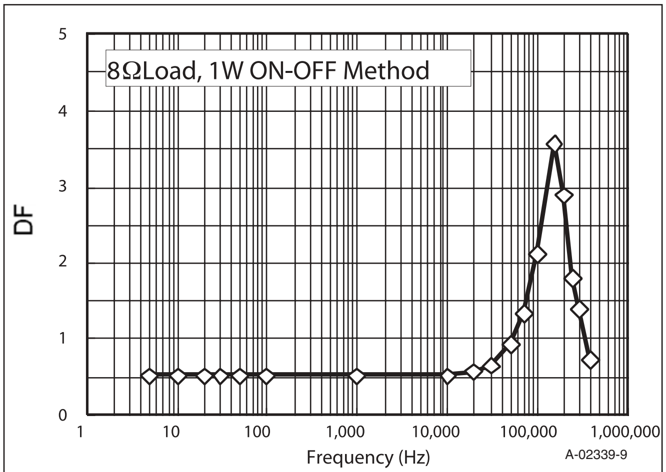

FIGURE 9: Damping factor.

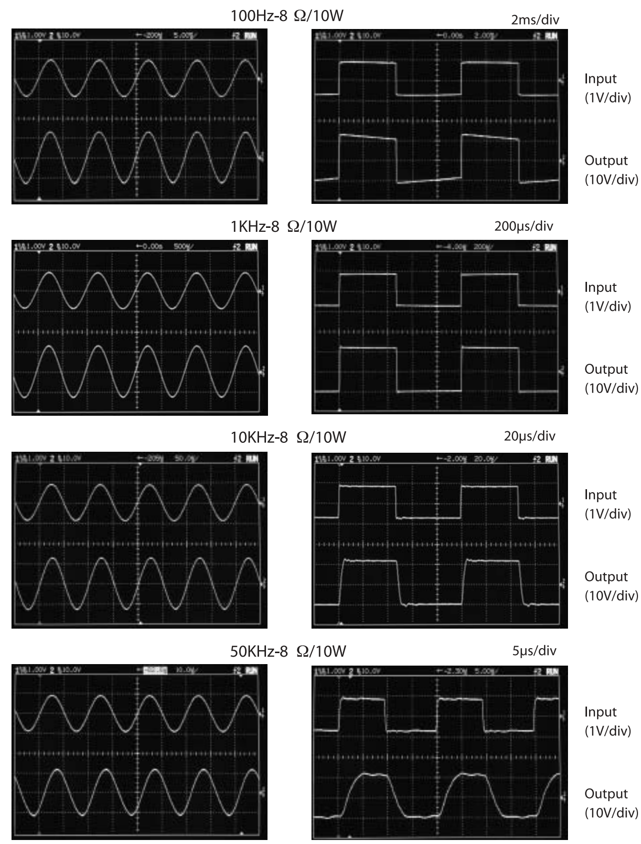

FIGURE 10: Output waveform. A-02339-10

• Side wall board

The side board, which is 430 × 57 × 12.7mm, is made of CORIAN, which is regularly used for kitchen sinks. You could replace it with a regular wood material such as oak.

• Metal feet

This solid milled aluminum metal foot by International Audio Group (IAG), Texas, is also my favorite component to match this chassis.

• DACT-made ATT with gold-plated metal knob

A DACT-made stepping ATT also brings a professional touch when you turn the metal knob, which clicks, so you can attenuate precisely in increments of a few dB. I had the knob, which was originally made by DACT, 18K gold-plated over the original stainless surface, through a metal plating company in San Antonio, TX.

• PTP Board

I first noticed this product (from IAG, Texas) advertised in *Glass Audio* magazine. I love this product because its simple and rigid structure matches my chassis structure. This fully eliminates the burden of wiring against a traditional wiring scheme, without attention to one–point grounding.

• Printed Circuit Board

The first stage (*Fig. 3*, *Photo 2*), and power supplies (*Figs. 4*, *5*, and *6*) are mounted over a PCB for the purpose of: 1) minimizing hums, 2) simplifying assembly and wiring even for beginners, 3) improving reliability, 4) enhancing maintenance, and 5) being flexible for a circuit modification. A separate functional unit structure also saves time since you can do this PCB assembly while waiting for the custom chassis to arrive.

• Power Entry Module

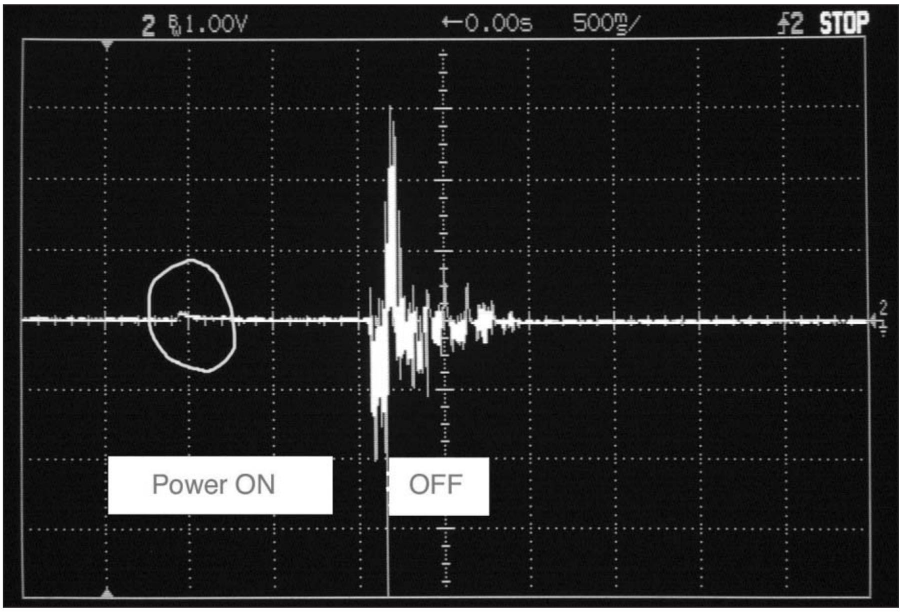

PHOTO 4: Noise voltage at speaker terminal (protected).

The power entry module is also a convenient component to save on extra wiring. Since the Plitron power transformer provides its own wiring leads, you can directly connect these leads to this module without any extra wire. This module provides a switch and a built–in fuse folder, thus saving space on the chassis.

TABLE 1
PARTS LIST

AMPLIFIER

PARTS	DESCRIPTION (MANUFACTURER, DEALER)	QTY.
Valves	KT88 matched quad (Svetlana/Tec–sol)	1
Valves	6N1P (Svetlana/Tec–sol)	2
Valves	Ei 12BH7AEG (Ei Elite/Tec–sol)	2
Socket	8 pin	4
Socket	9 pin	4
Output Transformer	PAT-4142-00 (Plitron/Tec-sol)	2
Operational Amplifier	TL072 (Texas Instruments)	2
Balanced driver	DRV134PA (Burr–Brown)	2
Resistor (KT88 cathode)	1Ω 1~2W 1%, alternative 1~10Ω 2W	4
Resistor (12BH7A grid)	150Ω ½W Carbon	4
Resistor (KT88 screen grid)	330Ω 1W Carbon, alternative 500W	4
Resistor (TL072 input)	1kΩ ¼W, 1% Metal Oxide (Tama Denki Kogyo)	2
Resistor (KT88 control grid)	1kΩ ¼W, 5% Metal Oxide (Tama Denki Kogyo)	4
Resistor (6N1P cathode)	2.2kΩ 2W Metal Oxide (KOA, Kaijin Musen)	2
Resistor (TL072 feedback)	10kΩ ¼W 1% Metal Oxide (Tama Denki Kogyo)	2
Resistor (12BH7A cathode)	15kΩ 5W Metal Oxide (KOA, Kaijin Musen)	4
Resistor (6N1P plate)	47kΩ 2W Metal Oxide (Radio Store in Akihabara)	4
Resistor (KT88 grid)	100kΩ ½W Metal Oxide, 5% Metal Oxide (Tama Denki Kogyo)	4
Resistor (6N1P grid)	100kΩ ½W Metal Oxide, 5% Metal Oxide (Tama Denki Kogyo)	4
Capacitor	0.33µF 630WV Film (www.angela.com)	4
Capacitor	1µF 100WV Siemens, Film (Kaijin Musen)	4
Electrolytic Capacitor	33µF 25V Tantalum Capacitor NEC	2
Electrolytic Capacitor	47µF 200V (Nichicon)	4
Relay	12V DC, 150Ω 2PDT (JAE CM04–D18D)	1
Toggle Switch	2PDT, 125V 5A, C&K 7301	1
Diode	100~1000V, 1A or equivalent	1

POWER SUPPLY

PARTS	DESCRIPTION (MANUFACTURER, DEALER)	QTY.
Power Transformer	754709, (Plitron/Tec–col)	1
Switching power supply	Output: 5V/2A, Input: 85–132V AC, COSEL, Gorilla YS1005A (YS512: discontinued) Docs: http://www.cosel.co.jp/	2
PCB	100×75mm 1.6mm thick PCB	4
PCB	40×60mm 1.6mm thick, double sided (Okoshi Denki)	1
MOSFET	IRFPC40, IR (Akizuki Denshi), or comparable with 2SK type MOSFET (Vdss = >600V, Ids = >5A, Rds = <1~2Ω) See MOSFET Databook by CQ Publishing Co. Tokyo	1
Diode	2NU41 Toshiba or 1000~1200V 2A equivalent	4
Diode	200V 1A equivalent or 10D1	3
Zener diode	12V 0.5W (Hitachi)	1
Zener diode	15V 0.5W (Hitachi)	2
Zener diode	30V 0.5W (Hitachi)	1
Zener diode	33V 1W (cascaded in series) (Hitachi)	2
Zener diode	150V 2W (Ishizuka Denshi or equivalent)	3
Resistor	1kΩ ¼~½W carbon	1
Resistor	1kΩ 1W carbon	2
Resistor	2kΩ 2W metal oxide	1
Resistor	5.6kΩ 1~2W carbon, alternative 4.7~6.2kΩ	1
Resistor	100kΩ ½W carbon, alternative 100~270kΩ	5
Capacitor	0.01~0.001µF 500V or 1kV ceramic	3
Capacitor	0.01~0.001µF 25V ceramic (TDK)	2
Capacitor	33µF 25V (NEC)	2
Electrolytic capacitor	47µF 200V Electrolytic Capacitor	4
Electrolytic capacitor	120µF 400V Electrolytic Capacitor, alternative 100~200µF, 250~350V	2
Electrolytic capacitor	270µF 550V (Nichicon)	2
Electrolytic capacitor	3300µF 16V (Nichicon)	2
ZNR	Matsushita, 150V AC, surge absorbing	1
Pin terminal	Teflon insulated	
Heatsink	LEX 20PB55–30, L = 55mm, H = 30mm, Thermal Resistance = 8.9° C/W, (Suzurando)	1
Potentiometer	25kΩ 0.5W, Bourns, or NEC, COPAL	4
Toggle switch	2PDT, 125V 5A, C&K 7301	1

(continued on 41)

• Miscellaneous

The MOSFET, heatsink, speaker terminals, resistors, capacitors, 9-pin sockets, wire and heat shrink tubes I used here were in my parts box, mostly purchased in Akiharaba area, Tokyo, Japan, as well as a few junk shops in California.

• Grounding Points

The PTP board and other PCBs have eliminated the so–called "one–point–grounding wiring method," though it would be very unclear where the grounding points should be for the audiophiles who are interested in copying this amplifier, prior to replicating this amplifier as completely as possible.

The following are the grounding points inside the chassis.

■ PTP board—tie a phase inverter ground layer with a 6N1P 9-pin using a silver-plated tin sleeve, then ground this point to the nearest spacer on the PTP board.

■ B, C power supply—choose any position out of four spacer holes, plating thin solder and ground this point using a 3mm bolt over a solder-plated

SOURCES

SVETLANA TUBE & PLITRON TRANSFORMER

Tec–Sol. Inc.
Hamamatsu shi, Wada cho 514
Shizuoka 435-0016 Japan
+81–53–468–1201
+81–53–468–1202 FAX
Tec–Sol HP, http://www.tec–sol. com/
PM Components HP, http://www.svetlana–tube.com/
Plitron HP, http://www.plitron.com/

PTP BOARD

International Audio Group 2790 Brighton Road,
Oakville Killeen, TX 76544
Tel (Fax): 905-829-5858

CUSTOM DESIGNED CHASSIS

EL Audio
Isehara shi, Sakuradai 3–9–39
Kanagawa 259–1132 Japan
Tel/Fax: +81–463–93–3090
Elaudio@k-asahi.jp

STEP ATTENUATOR, STAINLESS KNOB

Danish Audio ConnecT A/S
Skannerupvej 14
DK-6980 Tim Denmark
US Fax (+1) 248 282 0645
UK Fax (+44) 1270 964 2881
http://www.dact.com/

PCB

Okoshi Denki Seisakusyo
Sugito machi, Kinogawa 145-21
Saitama 345–0003 Japan
Tel/Fax: +81–480–38–0065

electrode.

■ ±12V DC power supply—ground a frame ground pin to the chassis through a spacer.

■ electrolytic capacitor (270μF 550V)—ground a negative terminal to either a fixing bolt on bracket using approximately 2″ long wire.

■ KT88 grid bias filter capacitor—ground a positive terminal to the nearest spacer point.

■ speaker terminal—tie a negative terminal with the nearest power-supply spacer position.

■ power entry module common ground pin—tie this pin to the ±12V DC spacer point.

ERROR CHECK AND ADJUSTMENT

• Wiring Error Check

After completing assembly, check the wiring at least once using a digital multimeter.

• Heater wiring

Without inserting any valves, turn the power switch on and measure the heater pin voltage of all the valves. It should be approximately 6.3V AC or higher (for example, 6.8V AC).

• Grid bias voltage

Measure the grid voltage of each KT88 tube counterclockwise all of the potentiometers. It should be approximately –65V. Then check that the voltage varies when making several turns of the potentiometer using a tiny Phillips screwdriver. Set the most negative voltage to avoid overrunning the KT88s.

• B+ supply

Measure the B+ supply voltage, which should be approximately 450V DC; it might be 445V, 452V, and so on. You can adjust this value of 450V as sharply as possible. Find a number of diodes and select the best one after screening. Note: the MOSFET might die instantly if you short the B+ terminal to the ground accidentally.

• KT88 idling current adjustment

Turn the power off and insert all the

(cont. from 40)

MISCELLANEOUS

PARTS	DESCRIPTION (MANUFACTURER, DEALER)	QTY.
Chassis	430 × 320 × 57mm, (EL Audio)	1
Metal foot	IAG (Texas, USA)	4
Power entry module	120V/250V AC, 10A, 50~60Hz, UL, CSA, VDE, Corcom, PS0S0SBX0	1
AC power cable	hospital grade, 3m long	1
Spacer	3j15mm long (Sengoku Densho)	20
Spacer	3j20mm long (Sengoku Densho)	8
5/16” bolt	2″ long	3
Hexagon bolt	3mm × 6mm long (Neji no Mizutani))	
Pilot lamp	12V ultra bright blue LED lamp, DUL–7HJT Sakazume Seisakusyo	1
RCA pin jack	(Kaijin Musen)	2
Speaker terminal	CU–T80 TRITEC	4
Wiring cable	Teflon insulated	
Insulation tube	Silicon rubber, ID = 4mm	
Heat shrinkable tube	(Sumitomo jushi)	
Side wall board	430 × 57mm, 12.7mm thick, CORIAN board	2
PTP board	140 × 80mm, 3.2mm thick, (IAG, Texas)	1

valves. Monitor the voltage drop over a 1Ω resistor with a digital multimeter. The measured voltage should be approximately 50mV. If not, carefully turn a potentiometer clockwise while monitoring this voltage. The voltage reading varies a little bit after the initial adjustment. After about an hour, repeat this adjustment procedure, keeping the power on. After this adjustment, the grid bias voltage deviation among the four KT88s should be less than ±0.5V or so, if you use Svetlana matched quad tubes.

LISTENING EQUIPMENT AND MUSIC

TEAC VRDS–50 CD player6N1P line amplifier
B&W Nautilus 802, JBL Exclusive, and Tannoy Kensington speakers

CLASSICAL:

Robert Shaw, "Amazing Grace," Telarc CD–80325
Maria Callas, "The Very Best of Maria Callas," EMI 7243 5 57230 2 4
Carlo Maria Giulini, "Mussorgsky—Pictures at an Exhibition," SRCR 2030
Itzhak Perlman, "Pable de Sarasate," GH 423 063–2

JAPANESE POPS:

The Boom, "OKINAWA–Watashi no shima," TOCT–24822
Nakamori Akina, "ZERO–album–untimate2," UMCK–1093

JAZZ:

Holy Cole Trio, "Don't Smoke in Bed," CDP 0777 81198 2 1

ROCK:

Roger Waters, "Amused to Death," CK 47127

MISCELLANEOUS

Test CD #2, *Stereophile* magazine

INTERNAL NODE VOLTAGE MEASUREMENT

Using a digital multimeter, monitor several key nodes of the whole circuit to see whether the amplifier is working properly.

• In–Circuit Node Voltage

The circuit diagram shows the internal voltage of several nodes—at an idling state, a maximum output state—helping you see whether the amplifier is running properly.

• Residual Output Voltage

MEASUREMENT EQUIPMENT

HP-8903B Audio Analyzer
Kenwood AG–204D Audio Generator
600Ω ATT HP–4437A
Homebrew 8Ω 50W two-channel dummy load
Fluke 8020B Digital Multimeter
HP–54600B Oscilloscope

Measure the speaker output voltage while setting an input volume at the minimum position, with a multimeter at mV AC range. My meter displayed 0.3mV and 0.5mV, respectively. No hum came out of my B&W 802 speaker, even when I brought my ear close to the speaker. If you install used KT88 tubes or the DC balance does not set properly, then this residual voltage might be larger than this value, such as 0.8mV or higher, bringing a hum out of your speakers.

• Switching Power Supply Noise

A ±12V DC switching power supply produced a pop noise out of the speaker system when I turned the power off (*Photo 3*). This is not adequate even for amateur use. The noise lasts for approximately 150mS with a 4.8V pp at 8Ω speaker output, bringing a rather big pop, measured with an oscilloscope.

This noise came from the power supply when I turned its power on or off, and transferred to the speaker via an IC output pin, a differential output, and finally a KT88 ground pin while the final tube was running with B+ supply. The protection circuit implemented consists of a power supply noise filter and the relay controlled short circuit of the speaker terminals. The relay closes to ground a hot speaker terminal, whenever you turn the power off. *Photo 4* shows results before and after this protection. The pop noise went away during turn-off.

Even with this improvement, the noise occurred during turn-on, and its level increased, caused by the relay chattering. To prevent this noise, leave the amplifier off for several minutes to cool the tubes down, and then turn the power on again. The pop noise will go away.

CHARACTERIZATION DATA

- Input versus output characteristics

The input sensitivity is approximately 0.2V RMS, which achieves maximum output power of 70~75W with an excellent linearity (*Fig. 6*). The clipping happens at 64W and the saturation appears beyond its value.

- Frequency response

Figure 7 shows excellent flatness and wide bandwidth beyond 100kHz and below 15Hz even at 50W output.

- Distortion

The distortion (*Fig. 8*) is rather high, since this amplifier employs non–NFB, though the frequency dependence is negligibly small.

- Damping factor

The damping factor (*Fig. 9*)—from the calculation of output voltage levels when 8Ω loading is on and off at 1W (2.83V RMS over 8Ω loading)—was approximately 0.5, showing a rather low value with the non-NFB circuit. The peak value was at 150kHz, implying the internal resonance induced by a stray capacitance and inductance.

- Output waveform

Figure 10 shows sine and square wave output forms at 10W with an 8Ω non–resistive load. No distortion was visible on sine wave reproduction, though an approximate 72° phase delay ($2\mu S$ delay = $2/10 \times 360°$) appeared at 100kHz.

No ringing appeared on the square wave as regularly seen by E–I cored conventional transformers even under non–loading. The rise time at 50kHz shows approximately $5\mu S$, forming a 100kHz square wave, since its rise time corresponds to one-half of a 100kHz cycle time under a non–resistive loading, no loading, and even a capacitive loading. ❖

VALVE AUDIO FAIR

I had a chance to showcase this amplifier at the Valve Audio Fair 2003 in Akinahabara, Tokyo. The audience of Japanese audiophiles that gathered in a small room numbered about 50, though another 20 people were in and out between the one–hour sessions. So the audience totaled about 150 or so throughout the two days. The setup included either the JBL Exclusive or Tannoy Kensington speaker system. In addition, I used a 6N1P line amplifier (published in *MJ* magazine, March 2000) to drive this amplifier as well. The test CDs were "Test CD #2," published by *Stereophile* magazine, and classical music, J–pops, jazz, and so on.

First of all, the sound from the test CD produced a channel identification signal using a bass guitar strongly enough to surprise a number of audience members. I believe that the sound of this amplifier shocked the audience, mainly because the sound from the speaker produced a real presence in terms of the width and depth of the stage.

Vented 8" Driver Subwoofer, Part 2

The authors finish construction of their vented box subwoofers and give the pair a listen. **By G.R. Koonce and R.O. Wright, Jr.**

The two boxes are built mirror- imaged in terms of driver lateral offset and vent exit side. The vent exits on the side farthest from the driver location. *Figure 13* shows a right-side view of the enclosure locating the front panel (FP), the back board, and the hole for the vent exit flare (box right is on your right as you face the front of the box). The front view (*Fig. 14*) shows the woofer mounting information for the box with the right side vent exit.

The other box includes the vent exit at the same location on the left side and the woofer mounting offset toward the right side. You should orient the driver with mounting screws on horizontal and vertical lines to align with the stiffeners. *Table 5* lists the sizes of the various panels that make up the box. *Table 6* lists the materials needed to build two boxes.

Also shown in *Fig. 14* are the locations of the FP corner blocks and the side braces. Note that the corner blocks on the wide side of the FP have double 45° angle cuts, while those on the narrow FP side are cut to fit against the wall with a single 45° cut. This allows the narrow FP side blocks to act as retainers for the T-nuts. The side wall braces, which would run into the folded vent duct, present a design problem, so you need to hand-fit them after installing the vent duct (documented later).

PHOTO 10: View of basic port structure through top of box.

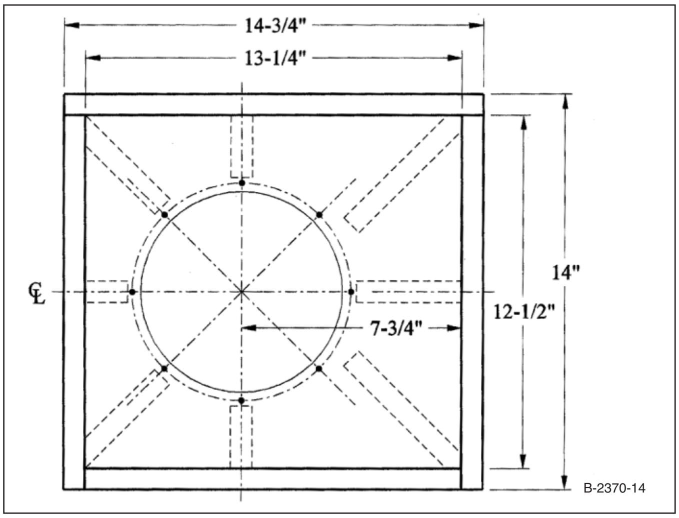

FIGURE 14: Front view of enclosure with port exit on right side.

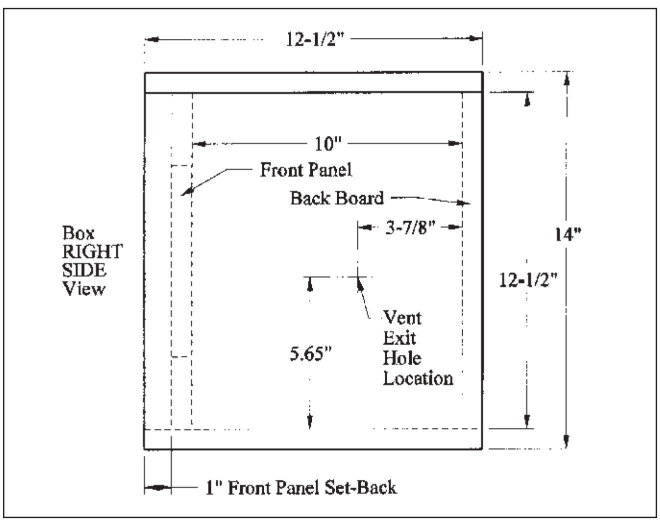

FIGURE 13: Right side view of enclosure showing port exit.

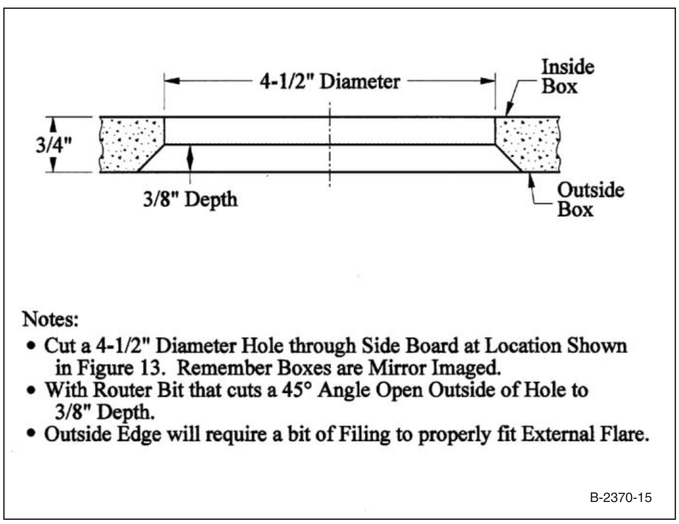

FIGURE 15: Details of hole to mount exit flare.

Figure 15 shows details of the hole used to mount the external vent duct flare. We used this approach to maintain the maximum side wall stiffness around the exit flare.

We fabricated the front panel as discussed in Part 1. Six of the eight T-nuts are retained by the stiffener blocks/braces. This was not practical for the two T-nuts at a 45° angle on the wider side of the front panel. For these T-nuts, we installed a #6 3/8″ pan head sheet metal screw right next to the T-nut and tightened it only to the point of touching the T-nut. We relieved the FP between the T-nut locations and also fabricated the side board containing the exit flare with the hole (*Fig. 15*) and screw holes to mount the external flare.

We mounted the flare with #6 ¾″ pan head sheet metal screws drilling the screw holes at this time. Experience shows that waiting is a smarter choice, because drilling the holes when the assembled duct structure is installed allows last-minute rotation of the structure to get the best positioning.

The assembly of these boxes starts by marking the nail locations for mating panels and pieces on the fabricated panels. Then you drill #51 drill (0.067″) holes for the panel nails. We marked the positions of stiffeners without drilling nail holes because we did not know the details of the stiffener's length. We were also unsure whether we could secure these stiffeners well enough to allow nailing into them.

To assemble all panels, glue both sides of the seam, clamp the panels in position, and then nail them together. Set all nails in from visible external walls below flush. Our assembly order was:

1. Glue the right side and clamp it into position on the bottom board, keeping the fronts flush and then nailing them.
2. Then glue FP and back boards and clamp them into proper position on the right side and bottom board, then nail. Be sure to install the FP that agrees with the vent exit location for the box under construction.
3. Glue the left side and clamp it flush at the front and nail it.

Don't install the top now, because you must construct the port duct and install most of the stiffeners and damping material pieces through the open top. Fillet the inside seams to ensure an airtight box now, because the vent duct assembly will make seam access difficult. Fillet with yellow glue that tends to suck into any air gap, and keep applying glue until a visible fillet remains after drying. Be especially careful where three panels join. You must consider these fillets later when fitting the stiffener blocks.

While the box is empty, clamp on the over-width top and draw the position of all panels on the top through the driver hole to identify where nail holes will be needed. Also, mark the location of the top panel brace.

CONSTRUCTION OF THE COILED VENT DUCTS

Next comes construction of the vent duct. It is likely you will not construct two identical ducts, thus complicating the hand-fitting of the panel braces. Once assembled, our ducts turned out to be rather stiff structures that actually helped to brace the box.

Figure 16 shows layouts of the port duct pieces straightened out for simplicity. Identified are the components used for the two available duct lengths; however, since the shorter duct is ultimately used, you will not need pieces 7 and 8. You need to prepare the components as necessary to ensure the assembled duct has a smooth inside surface.

The 3″ drainpipe components are manufactured in either styrene or PVC. We initially started gathering the components in styrene, which seemed a bit smaller and lighter. The hardware stores reported the styrene parts are on the way out, so we ended up with a combination of styrene and PVC parts. Don't do this. Buy all PVC parts. The styrene and PVC parts have the same pipe ID, but a slightly different OD. We needed to sand all PVC parts that fit inside a styrene part—a time-consuming procedure you'll prefer to avoid.

We did not know which of the two duct lengths would be better, so we tried both. Thus we assembled parts 1 through 6 in *Fig. 16* and installed the duct. We could then try the two different internal flare approaches to test both lengths. Even knowing the finished length, you shouldn't complete the duct assembly at this time because you need the open space to work through. Referring to *Fig. 16*, assembly of the basic duct is as follows:

1. Wrap just the machined lip on the inside end of the external flare (1) with masking tape until it mates snugly with the 45° elbow (2). The adhesive bonding will occur on the plastic portion of the flare. The tape wrapping is to ensure the inside IDs line up properly.
2. Cut the 3″ piece of PVC pipe (3) and verify that it fits snugly into the two 45° elbows (2) and (4). The two elbows should butt together covering this PVC pipe section.
3. Verify that the 90° street elbow (5) male end fits snugly and fully into the 45° elbow (4).
4. Verify that the male end of the next 90° street elbow (6) fits snugly into the female end of street elbow (5). This is as far as the duct is initially assembled. The internal flare will mate with the female end of this elbow (6).
5. Assemble, without adhesive, all the parts (2 through 6) without the external flare (1).
6. Insert the external flare (1) from the outside and slide elbow (2) on to it fully. Now rotate the parts until the duct just touches the bottom of the box. Street elbows (5) and (6) should just about touch the far wall. Slide the internal flare (9) into street elbow (6) and twist until the edge of this flange is just over 1″ from the back board. This includes aligning the flare's mounting screw holes if already drilled.

Photo 10 shows a view through the open top of the box of the duct structure at this time. *Photo 11* shows a view of the duct structure taken through the driver hole with components (7) and (8) added for the longer duct length.

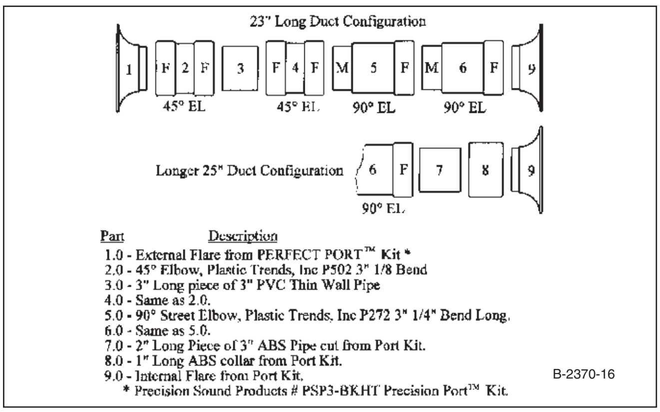

FIGURE 16: Schematic sketches of the port duct layouts.

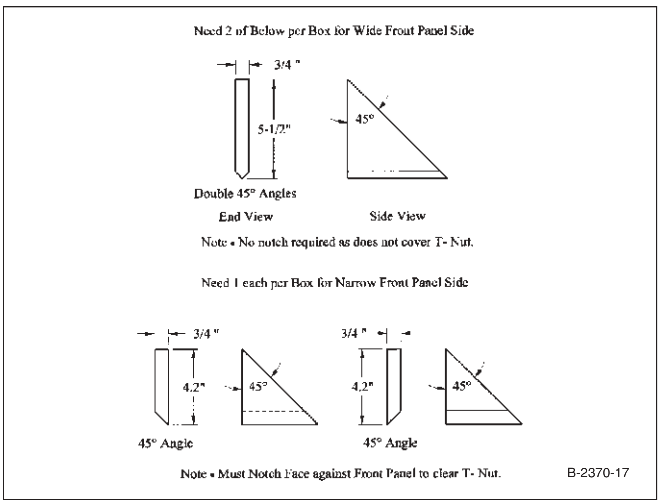

FIGURE 17: Corner stiffener blocks for boxes.

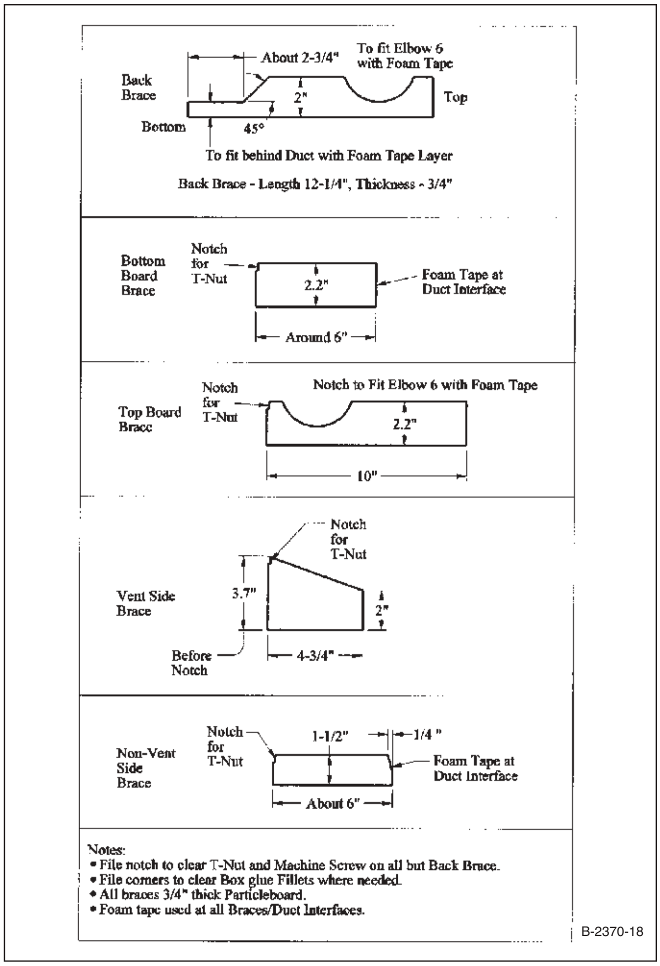

FIGURE 18: Side braces for boxes.

7. Once you have the duct layout set, remove the internal flare (9) and scribe the various pieces to show their proper rotational alignment, including the external flare (1) to the first elbow (2).
8. Mark the areas contacted by the duct structure on the bottom and far side boards. The duct may not quite reach the far side, but mark the area where it comes close.
9. You can then snake the entire duct structure out of the box via the external flare hole.
10. Cover the area on the bottom board where the duct structure will touch with thin double-sided foam tape to help mount the duct and prevent rattles. Apply thick double-sided tape to the far wall to prevent any rattle, even though the duct may not quite reach it. On one of our boxes the duct reached this tape, while on the other it did not.
11. We used Liquid Nails, the adhesive recommended for assembly of so many different materials. Each joint is separated and a thin coating placed on the inside of the female portion of the joint. This is just enough to fill the internal joint to form a smooth inside diameter. Apply a liberal amount of adhesive to the male portion of the joint and then assemble and rotate the joint to align the scribe marks. Wipe any excess adhesive off the outside of the joints.
12. Once you have assembled the duct, cover the inside mounting face of the external flange (1) with a light coating of silicon rubber to produce a seal and add some mounting strength. Then snake the duct into the box, press it into the foam tape on the bottom board, and install and tighten the external flange screws. Leave the entire assembly alone while the adhesive sets up.

STIFFENING THE BOXES

At this point, all the stiffening blocks and braces are developed and those not associated with the top panel installed. *Figure 17* shows the shapes for the corner stiffener blocks. Note that on the narrow FP side the top and bottom blocks are different.

Figure 18 shows the approximate dimensions for the panel braces. The exact shape of the vent duct structure will set the length and other aspects of most of these braces. You must hand-fit each brace which will likely be different for each box. The duct structure and these braces make building these boxes a time-consuming task.

Note that we installed the corner blocks and most braces by gluing and clamping. Any time a brace "touched" the vent duct, we cut it back slightly and used double-sided foam tape at the interface. The intent was to make the vent duct part of the box bracing system. Remember that you must file all FP blocks/braces that retain a T-nut to clear the T-nut with a slight margin to prevent rattle. Also, provide clearance

PHOTO 11: View of longer port structure through driver hole.

for the driver mounting screw, which sticks through the T-nut slightly.

A good order for fabricating and installing the blocks/braces is as follows:

1. Bottom board brace. Cut this in length to butt against the vent duct with foam tape at the interface. File the FP end to clear the T-nut and the bottom/FP glue fillet, then glue the brace and clamp it into place.
2. Bottom corner triangular block on wide FP side. The double 45° angle cut mates the side/bottom interface. You must file the block to clear any glue fillets, but it does not cover a T-nut. Install it by gluing and clamping.
3. Bottom corner triangular block on narrow FP side. The single 45° angle cut goes against the side board. You must file the block to clear the T-nut and glue fillets, then glue and clamp it into place.
4. Brace on side with vent exit. Cut this brace to the size shown in *Fig. 18*. You must file it to clear the T-nut and any glue fillets, but it does not interface with the duct structure. We glued and clamped it and also retained it with two nails through the side board.
5. Brace on side without vent exit. Cut this in length to butt against the vent duct with foam tape at the interface. File the FP end to clear the T-nut and the side/FP glue fillet, then glue and clamp it into place.
6. Back board brace. This brace, which will vary considerably in shape based on your exact duct implementation, runs vertical just to the wide FP side of and against the top brace. You must cut the bottom end low enough to slide under the duct with a layer of foam tape at the interface and file it to clear the bottom/back glue fillet. Near the top, this brace has a semicircular cut to retain the vent duct at the far end of the second 90° elbow (6). We again used foam tape at the interface, so this brace retains the duct to help prevent it from vibrating. Install this brace by gluing and clamping. *Photo 12* shows all installed braces and damping blocks prior to top installation.
7. The top panel brace (not installed at this time). You must notch this brace to clear the T-nut at the FP end. It also has a semicircular cut to interface with the vent duct elbow (6) via foam tape. GRK could see no way to install this brace once the top was in place, so we installed it after the blocks of damping material, but before the top.

We fabricated the two top triangular corner blocks, but did not install them until after the top. You should file the wide FP side block to clear any glue fillet on the top/FP interface. File the narrow FP side block to clear the T-nut and glue fillets. You will glue and clamp these blocks into position through the driver hole once you have installed the top and filleted its seams.

DAMPING MATERIAL FOR THE BOXES

The design requires absorption damping to meet the intended response. We did this by applying a 1″ thick Owens-Corning #705 material layer to the walls. You may decide to substitute your favorite damping approach. The #705 material is easily marked with a dull #2 pencil and cuts easily with a serrated bread knife.

Before installing the damping mater-

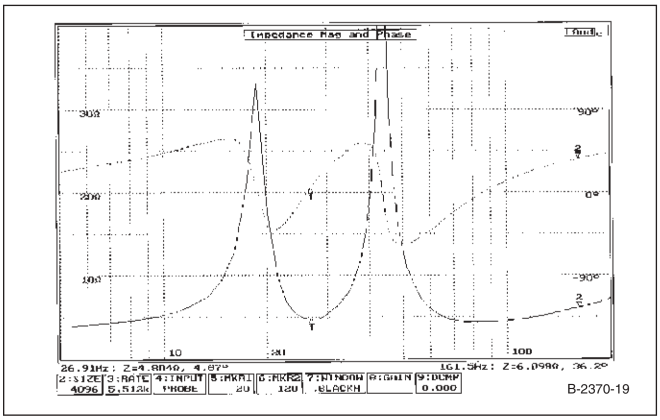

FIGURE 19: Impedance test tuning box A with 25″ duct.

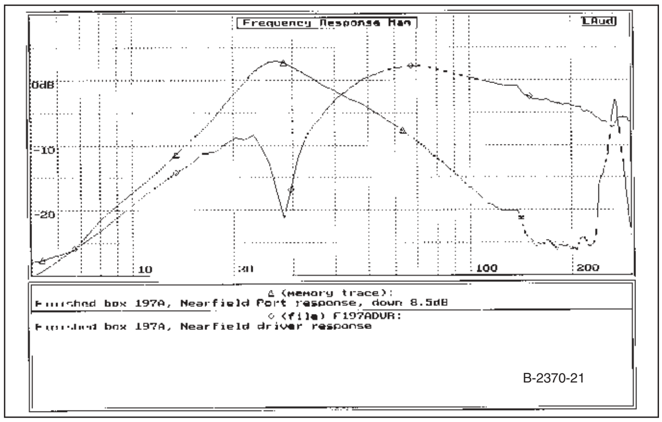

FIGURE 21: Driver and port responses for finished box A.

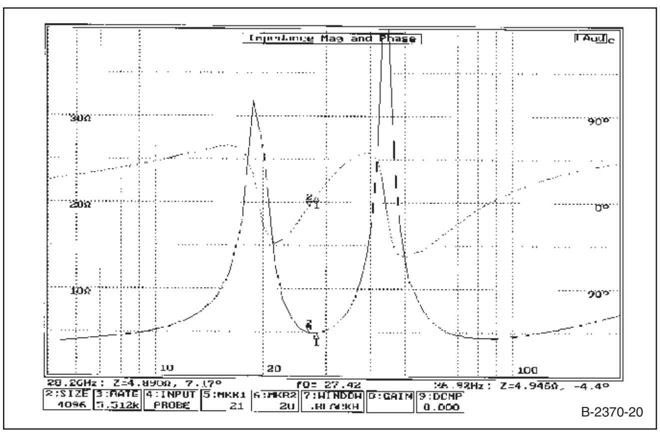

FIGURE 20: Impedance test tuning box A with 23″ duct.

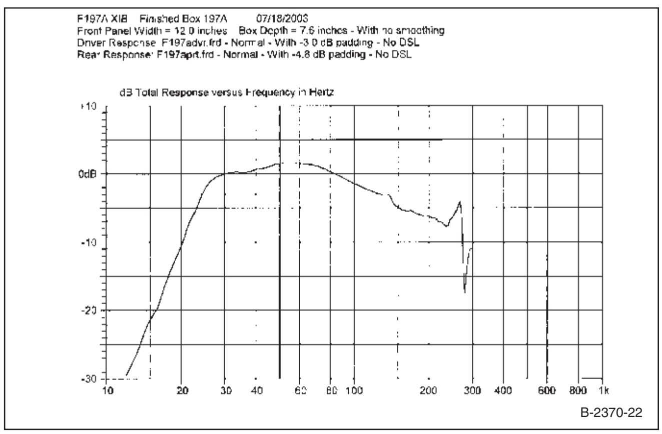

FIGURE 22: Measured response of subwoofer box A.

ial, you need to install the driver wire. Drill a hole in the back board ¾″ up from the bottom board and ¾″ in from the side board containing the vent exit. We used a 5⁄16″ hole and installed a #16 Zip cord sealed with silicon rubber.

We covered all walls except the FP as much as possible with 1″ thick OC #705 damping material. *Table 7* shows the basic sizes of the pieces used. The term "vent side" means on the box side where the vent duct exits. You must notch all these pieces to clear braces, blocks, and the duct structure. Some will require shaving their thickness down to fit between the wall and the duct structure. We allowed the duct structure to press right against the damping pieces to further prevent duct vibration. We found it much easier to install most of these pieces by cutting them in two to clear the numerous obstacles. We installed most damping pieces before the top panel using yellow glue in the following order:

1. Push the two back board pieces right to the bottom so they end 1¼″ below the top to allow the later filleting of the top board seams. You must notch the piece on the vent side to clear the speaker wire.
2. We installed the two bottom board pieces pressing against the back pieces.
3. We installed the piece for each box side, below the side brace, against the bottom board and back board pieces.

Fabricate the two damping pieces for the top board and the upper damping piece for each side wall at this time, but do not install until the top installation is complete. To keep the box dimensions to a minimum, the design did not guarantee the needed space between the panels and the internal duct for a 1″ wall covering. GRK found that some damping pieces for the top and the side board needed to be notched to clear the internal flare. Investigate this interference and correct it now before installing the top.

In the next section you will be building with the shorter 23″ duct, so you only need to assure clearance for assembling that configuration. Do not finish the vent duct construction at this time, as you need the working room. You can complete installation of final corner blocks and damping pieces along with vent duct through the driver hole.

To install the top panel brace, glue it to the FP and the back board brace, making sure it is flush with the top. Drive a single nail through the FP into this brace. At this point, the inside of the box should appear as shown in *Photo 12*.

TUNING TESTS OF BOX A

With little hope of a major duct length change, we tested the two available lengths to determine the better option. With the boxes assembled to the status above, we temporarily installed driver unit A for tuning box A by completing the desired duct structure, then installing the top board with carpenter clamps that seemed to provide an acceptable seal.

We started tuning with the longer (25″) duct length looking for f_B in the 30Hz region. The impedance plot (*Fig. 19*) shows f_{MIN} at 26.9Hz, lower than expected. We unclamped the top and changed the duct to the 23″ length. With the top replaced, the impedance plot (*Fig. 20*) shows f_{MIN} had risen to 27.4Hz, still a bit low and less change than we expected.

A near-field measurement of the cone response (not shown) indicated the actual f_B was 28.3Hz. This is a bit below the design value, but acceptable. The equation provided by Precision Sound Products appears inaccurate for

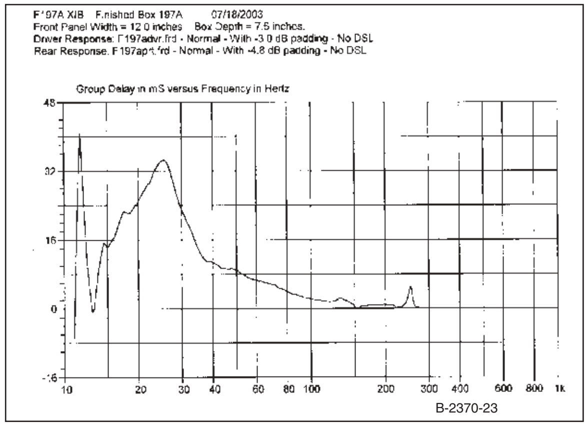

FIGURE 23: Measured group delay of subwoofer box A.

some reason; perhaps it does not account for the fact that the box is damped. Alternately, measurement of the length of a curved duct along its centerline may not indicate the effective length. We continued our work using the 23″ long duct.

We did not final-test the box at this time, because the internal construction was incomplete. The damping material on the top board may change the tuning slightly, as the edge of the internal flare may be right against this material. Also, the clamping may not have produced an airtight seal on the top board. We removed driver unit A to complete its construction.

TOP BOARD INSTALLATION ON BOXES

Now drill nail holes in the top board to match all mating panels and the top brace. The box should appear as shown in *Photo 12*. Since glue-filleting the top seams is difficult, we applied excessive glue to the top board where it will mate other panels, then clamped the top into the proper position, flush with the box front and overlapping both sides, and then nailed it. Before nailing into the top brace, be sure to clamp it at the front through the driver hole to secure its position. Set the nails below flush, and then position the box top down.

Reaching through the driver hole, try to form the excess glue into seam fillets with your finger and let the glue dry with the box inverted. Later, working through the driver hole, repair any fillet that needs it. Once the fillets are complete, install the two corner FP stiffener blocks. Once the glue on these has dried, fillet these joints.

Next, working through the driver hole, install the two pieces of damping material on the top board. You should cut these pieces in half lengthwise to get them through the driver hole. Finally, install the two upper side damping material pieces pressed against the top pieces.

After installation of the top, its stiffener blocks, and damping material, it is time to finish the port duct. Through the driver hole, finish the vent ducts by adding just the internal flare (9) into the end of the existing structure. As you did with the external flare, tape the machined end of the internal flare till it fits snugly into street elbow (6).

The adhesive bonds on the plastic, so the tape just assures the inside aligns smoothly. Again, apply a small amount of Liquid Nails adhesive inside the female portion and lots of Liquid Nails on the male portion of the joint. Allow the adhesive to dry.

Use a flush-cutting bit to route the over-width top flush with the sides. Next, fill the nail heads and sand the boxes. You can apply your favorite finish to the boxes if you choose. Then you can install the drivers. Be careful attaching the wires to this driver, because TBspeakers has highly underestimated the size of solder terminals needed on a subwoofer driver. We installed the drivers dry with no leakage. If you have a leakage problem, you could use a thin

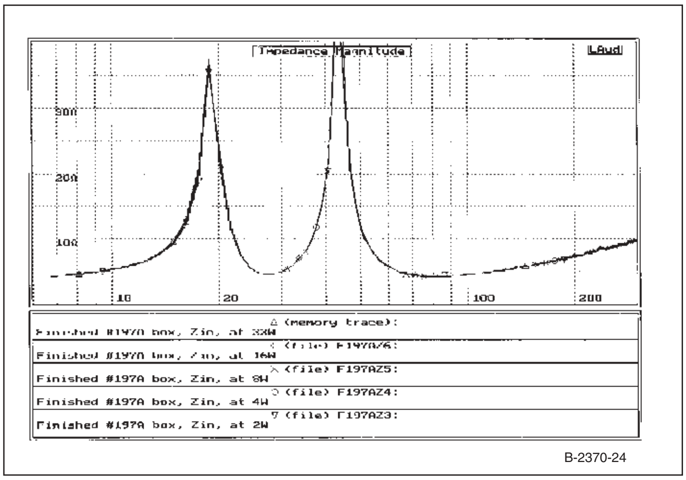

FIGURE 24: Input impedance at various power levels for subwoofer box A.

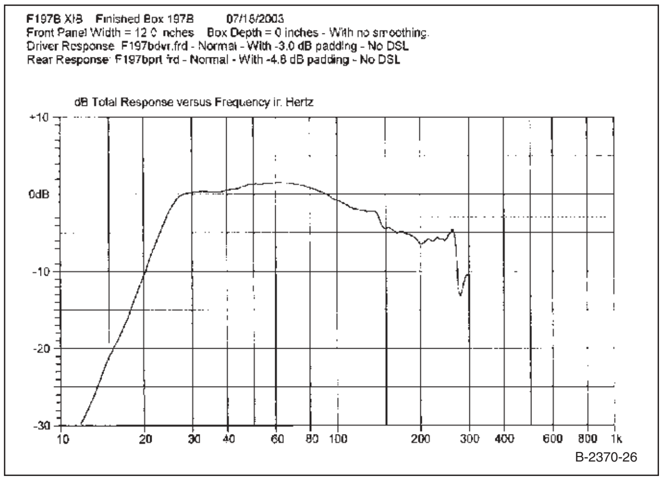

FIGURE 26: Measured response of subwoofer box B.

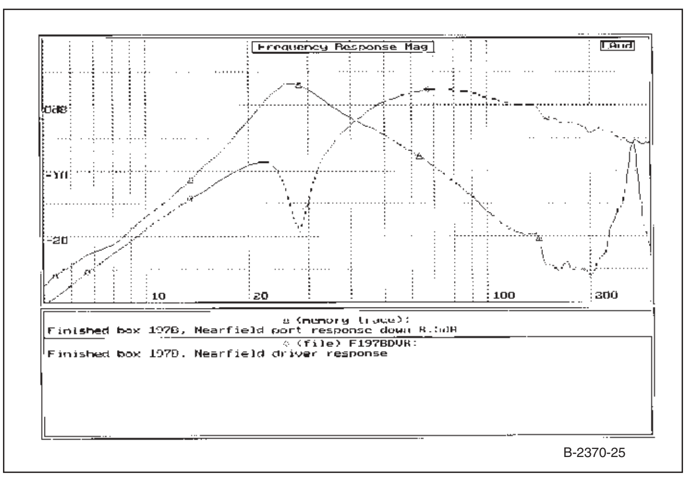

FIGURE 25: Driver and port responses for finished box B.

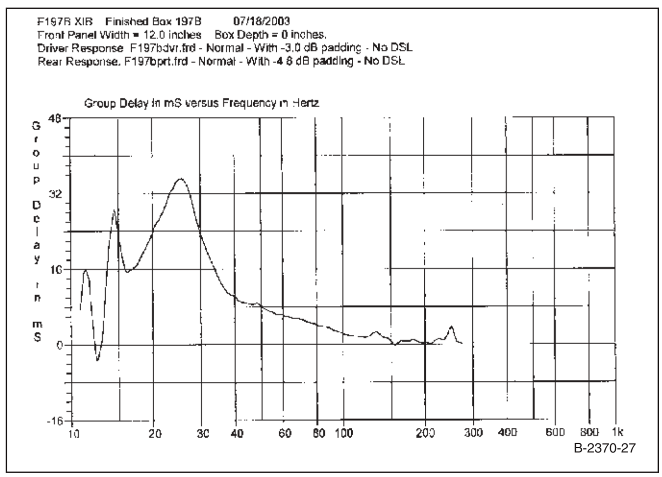

FIGURE 27: Measured group delay of subwoofer box B.

coat of silicon rubber on the back of the driver rim and cut it later if you need to remove the driver.

You can now install the front grille cloth by stapling it to the front edge of the box. Then cut, finish, and install front trim pieces around the grille frame. We left off the grille cloth so we could observe cone motion.

We added barrier strips on the backs of the boxes to terminate the speaker wires. *Photo 13* shows a rear view of a finished box and *Photo 14* a front view without grille cloth.

TESTING THE FINISHED SPEAKERS

We tested the finished boxes for response via near-field testing. *Figure 21* shows the driver and cone responses corrected for area difference for box A. Within the testing accuracy, f_B is 28.3Hz with the woofer response showing a good dip at this frequency. The port response is clean and smooth, but exhibits a high resonant peak near 270Hz.

Figure 22 shows the system response, without diffraction spreading loss, showing a usable response from 24 to over 100Hz. Here you can see the response droop above 70Hz due to peaking in the driver. This combined with the low f_B results in a lower f_3 than was expected. *Figure 23* shows the system group delay; again ignore anything below 30Hz.

Reference 3 develops the concept that looking at the input impedance of your VB is a good way to establish just how "good" your port is at handling power. At low power you get the proper double peaked curve with the dip at f_{MIN} very close to the box tuned frequency f_B. As you increase the power level to the driver, the first sign of port trouble will be a drop in magnitude of the lower-frequency peak. When your port

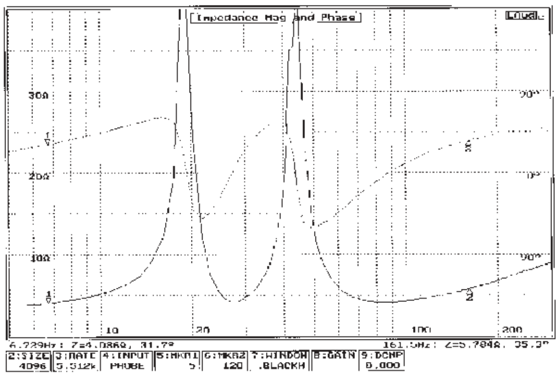

FIGURE 28: Input impedance for subwoofer box B.

PHOTO 12: View of bracing and damping before top installation.

fails completely the lower peak will disappear, leaving in effect a "leaky closed box."

While our test setup is not intended for high power testing, we did manage to measure input impedance on subwoofer box A from low power up to 32W in 3dB steps. *Figure 24* shows the shape holds constant, indicating this duct design is solid to at least the 32W level. How far above this power level the port can sustain we do not know, but at 32W the subwoofer was becoming rather loud.

We repeated the same testing on finished box B using driver unit B. *Figure 25* shows driver and port responses, *Fig. 26* the system frequency response, and *Fig. 27* the system group delay. Performance is nearly identical to box A over the subwoofer frequency range. *Figure 28* shows the input impedance for this box.

These subwoofers provide a usable response from about 24Hz to just over 100Hz with a slight peaking in the 40 to 80Hz range. This is a better performance than we had expected from the TBspeakers 8″ driver in a small VB.

LISTENING SYSTEM AND SOURCE MATERIAL USED

We installed the subwoofers in a two-channel stereo system using a fourth-order Linkwitz-Riley electronic crossover (Applied Research and Technology, Model #310, available through Parts Express). We set the crossover (CO) frequency at 110Hz throughout the listening and positioned the two subwoofers in the normal stereo positions with small two-way satellite speakers (boxes #1 and #2 with modified COs from reference 7) sitting on top of the subs. The boxes were away from all walls. The system driving both the subs and satellites contains a third-order infrasonic filter at 18Hz.

Our listening sources were music CDs and SACDs without movie or other special-effect soundtracks. In general our material was the same we used to evaluate the 12″ IB subwoofer[1].

With the electronic CO inserted into the test system, you must adjust for the relative sensitivities of the subwoofers and the satellites. The 4Ω satellite drivers are rated at 90dB/2.83V/m but the COs have been modified, lowering the sensitivity to perhaps 88dB/2.83V/m.

The 4Ω TBspeakers drivers are rated at 87dB/2.83V/m but in a questionable test showed 85dB/2.83V/m with no further loss due to the alignment. We rated these subwoofers at about 86dB/2.83V/m meaning the subwoofers are a couple of dB less sensitive than the satellites.

When we set the CO low– and high-frequency gains at the same level the sound was not acceptable, and making changes of a dB or two did not cure it. When we checked the amplifier gains we found the satellite amplifier had 8dB more gain than the subwoofer amplifier. When we corrected this gain difference, the sound was fine. This is a condition, along with one amplifier possibly inverting, that you must consider. With a fourth-order CO, both the subwoofers and satellites should be driven with normal phase polarity.

Figure 29 shows a block diagram of the listening system hookup. Note the average reading wattmeters are only on the satellites. We used small LED bar graph displays covering 0.5 to 256W peak (at 4Ω) in 3dB steps to monitor the subwoofer input level.

TABLE 5
SIZES OF PANELS FOR ONE BOX

QTY	ITEM AND SIZE IN INCHES		
1	Front panel	13¼ by 12½	(cut from 12½″ strip)
1	Back board	13¼ by 12½	(cut from 12½″ strip)
1	Top	14¾ by 12½	(cut 14⅞″ from 12½″ strip)
1	Bottom	13¼ by 12½	(cut from 12½″ strip)
2	Sides	13¼ by 12½	(cut from 12½″ strip)

TABLE 6
PARTS REQUIRED TO BUILD TWO SUBWOOFERS

QTY	ITEM
1 sheet	¾″ Industrial grade particleboard (49″ × 97″) cut into strips
2	TBspeakers W8-740C subwoofer drivers
16	10-24 pan-head machine screws 1″ long
16	10-24 T-nuts
4	#6⅜″ pan head sheet metal screws (to retain T-nuts)
8	#6¾″ pan head sheet metal screws (to mount external flares)
	Silicon rubber (to seal external flare and speaker wire)
8′	#16 Zip cord
Box	Elco #V2061 or equivalent 1⅝″ long panel nails
	Yellow glue (particleboard assembly)
	Liquid Nails adhesive (for assembly of port duct)
	Thick and thin double-sided foam tape (port duct mounting)
	Grille cloth (need two pieces bigger than 14″ × 14¾″)
	Cover strips for around grille frame
	Owens-Corning #705 (4′ × 8′ sheet) or other damping material
2	Barrier strips to terminate driver wire
	Sheet metal screws to mount barrier strips if used
4	45° 3″ PVC thin-wall elbows — see *Fig. 16*
4	90° 3″ PVC thin-wall street elbows — *see Fig. 16*
Some	3″ PVC thin-wall tubing — need short sections, see *Fig. 16*
2	3″ ID #PSP3-BKHP Precision Port™ kits — *see Fig. 16*
Some	Masking tape (to match pipe outside diameters)
	Optional feet or spikes for bottom of enclosure

TABLE 7
BASIC SIZES OF OC #705 DAMPING PIECES FOR BOXES

WHICH PIECE	BASIC SIZE IN INCHES
Back piece on non-vent side	11¼ by 5⅞
Back piece on vent side	11¼ by 6⅝
Vent side piece at bottom	9 by 5
Vent side piece at top	9 by 4⅞(installed after top)
Non-vent side piece at bottom	9 by 4¾
Non-vent side piece at top	9 by 4¾ (installed after top)
Bottom piece on non-vent side	9 by 5⅛
Bottom piece on vent side	9 by 7¼
Top piece on non-vent side	10 by 5⅛ (installed after top)
Top piece on vent side	10 by 7¼ (installed after top)

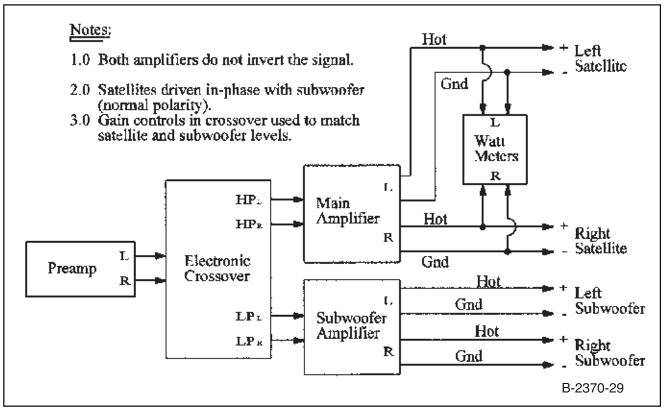

FIGURE 29: System block diagram of listening system.

LISTENING RESULTS WITH THE SMALL SUBWOOFERS (BY GRK)

These subwoofers sounded good with no buzzes or rattles. Drums sounded fast and taut and the subwoofers integrated well with the small satellites. We limited the playing level by watching the subwoofer cone excursion. The system did not seem able to play as loudly as I remember with the single 12″ driver IB subwoofer last year. Since this "opinion" involves a year old perceptual comparison it is highly suspect. Also, I was being cautious and not really pushing the 8″ drivers to their limit.

The system will clearly play loud enough that, barring very solid apartment walls or very tolerant neighbors, you could break your lease! They played loud enough for enjoyable listening with the drum strokes on "bass heavy" CDs showing peaks to the subwoofers in the 256W range. I heard no indication that the subwoofer was being limited by the port "packing up" or that the driver was doubling. The fact that the subs produced good-sounding drums at 256W peak input is not proof the port "holds up" to this power level. If the subwoofers converted fully to closed boxes they might still produce these drums.

I had previously identified a CD (Rykodisc RCD 10206, Mickey Hart, Planet Drum) which had a low-frequency "Earth Drum" in one cut. Testing had indicated the basic frequency of this drum was at 30Hz or below. As the drum sound is sustained a fair amount of time, I limited the peak power level to near 128W. At this level, the Earth Drum was clearly audible, but did not seem as prominent as I remember on the 12″ IB subwoofer; again a year-old perception.

Once I had overcome my initial caution, the system would play classical orchestral music as loudly as I dared go with the 12″ IB subwoofer as indicated by the average power level to the satellites. The flared ports do produce an unexpected effect on drum strikes. Listening on a pair of small subwoofers with non-flared ports, I noted each drum strike is very audible at the port exit and is accompanied by a noticeable air blast. Listening at the flared port output of these boxes, you hear little drum sound and 2″ back from the port you feel no air blast. Putting my fingers into the port revealed the expected air blast so the port was not "packed up." I was impressed with what the flares do for a port, which is very worthwhile for subwoofers.

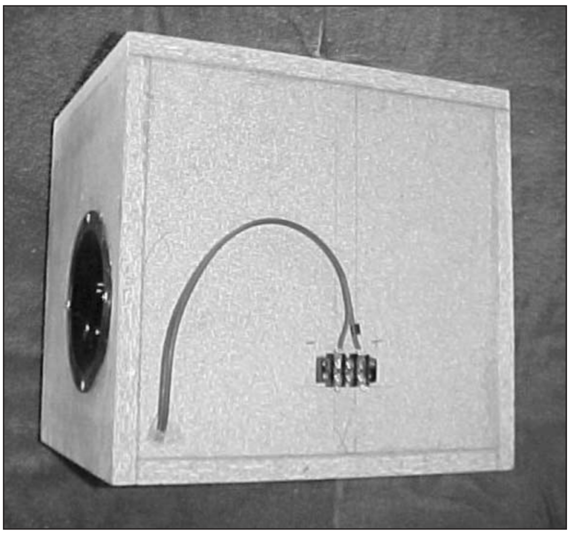

PHOTO 13: Rear view of the completed subwoofer.

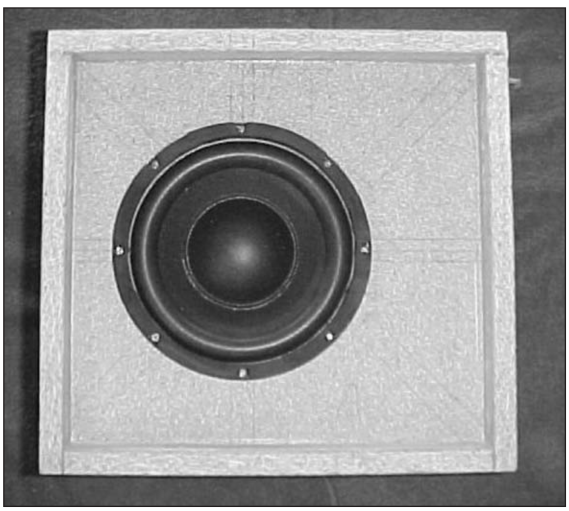

PHOTO 14: Front view of the completed subwoofer without grille.

OPTIONS AND CAUTIONS

With a pair of subs, it is possible to increase the maximum available acoustic output by locating the two subs together. This takes advantage of the correlative nature of bass signals and can raise the maximum acoustic output by 3dB. Placing the two subs together in a corner of the room produces the highest acoustic output capability. You should review articles covering subwoofer placement for the characteristics of the various placement options.

Remember these are vented box systems and thus subject to excessive cone displacement if driven with infrasonic signals. It is recommended they be used with a system containing an infrasonic filter.

If you use the Owens-Corning #705 damping material, or any other fiberglass based material, remember to take the proper precautions. We also recommend transporting the subwoofers laying on their backs to prevent any fiberglass that shakes loose from getting into the driver. ❖

REFERENCES

7. Koonce, G.R., and Wright, Jr., R.O., "Simple Satellites," *aX* May 2003, p. 32, and June 2003, p. 44.

Tube Audio Construction Tips: Part 3: Metalwork

Here are some tricks of the trade for fashioning a good-looking chassis.

By Graham Dicker

Chassis and metalwork often provide a challenge for many enthusiasts. My simple answer is to purchase "C" channel building offcuts at around $1 per meter, and then cut them into chassis–size lengths. You can use the larger 250mm-wide channel for power amplifiers and the smaller 100mm-wide channel for preamps. The channel comes zinc-plated and will resist the environment well. You can finish it with paint, powder coat, or chrome or gold plating, depending on your budget (*Photo 1*).

You can also bolt this same "C" channel onto a blank rack panel to make a low-cost tube rack chassis. I often use an inverted "C" channel and bolt on a Bakelite top. This makes hole drilling easier, and the timber end plates add quality to the cabinet's appearance (*Photo 2*). For many simple projects, you can use a jiffy box or die cast aluminum box, but at a greater expense.

WORKSHOP GADGETS

I am also fortunate to have purchased a combo type sheet-metal working machine. These are available in Australia at Paramount Browns Dry Creek Adelaide for around $695 AUD. They represent fabulous value for the money and are ideal if you have the workshop space. The units include a 30″ guillotine, adjustable pan-brake, and a sheet-metal roller. These allow you to fabricate just about any conceivable chassis and cabinet (*Photo 3*).

Another gadget I have made for my workshop is a homemade spot welder (*Photo 4*). You can find complete plans at John Bump's and Kurt Bjorn's web sites (http://www.frii.com/~katana/spotweld.html, http://www.5bears.com). The welder is easy to make, requiring a few discarded microwave oven transformers, a few parts, and an afternoon's work.

One technique I use when producing a chassis combines the use of a hacksaw, shears, tin snips, straight edge, and a well-oiled wood plane. This allows me to mark out and roughly cut up a large aluminum sheet (with the shears or saw) and then produce a beautiful straight edge with the wood plane. No damage appears to be done to woodworking tools when they are used on ordinary aluminum sheets or extrusions, and it saves a lot of filing to get a smooth, straight edge. It is important to use lubricating oil when using these tools.

Another woodworking tool that I find highly useful in producing straight or right-angled surfaces on aluminum extensions, is the circular sanding disc or the belt sander to which the disc is usually attached. The sander can save a lot of time removing jagged edges, or removing metal quickly.

For round holes for tube or canon

PHOTO 1: A selection of "C" channel showing various finishes and sizes.

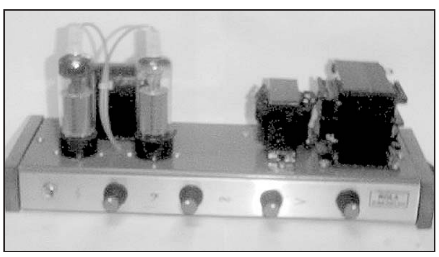

PHOTO 2: A guitar amplifier using "C" channel and timber endplates.

PHOTO 3: Combo type sheet-metal working machine.

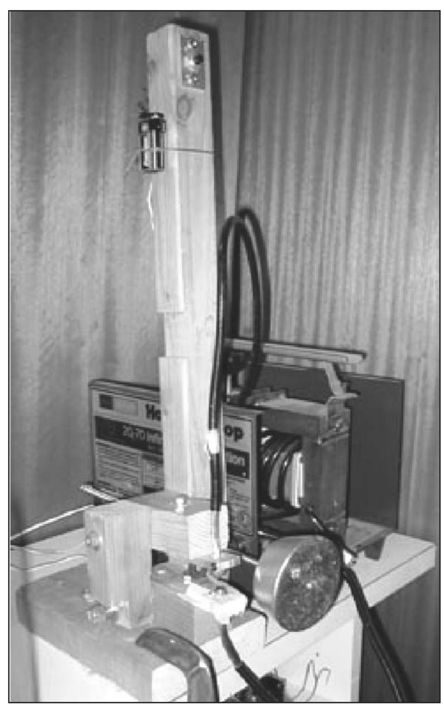

PHOTO 4: Homemade spot welder (photo courtesy of John Bump).

sockets, you can also use a woodworking hole saw, which can only be used with light gauge aluminum up to 16 gauge. It is important to use some lubricating or cutting oil. Without the oil, it can take about 5–6 minutes to cut a hole, which will often be oversized and ragged, and in all probability, you will damage the cutter. With the cutting oil, it takes only 15 seconds or so, and the hole is clean with little or no damage to the cutter. There are two (possibly more) different cutters on the market: one is a low–cost Asian product (*Photo 5*) that is not the most stable and does not produce clean holes. The second is a tungsten-tipped one that produces excellent results (*Photo 6*).

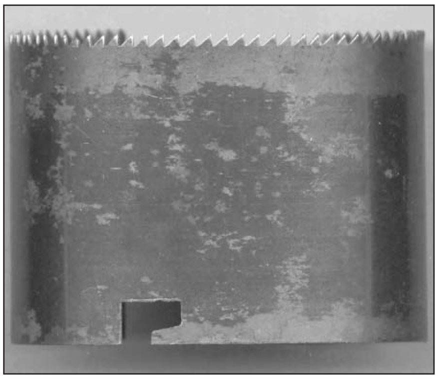

PHOTO 5: Low-cost Asian cutter.

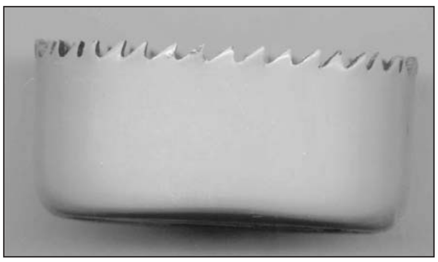

PHOTO 6: Tungsten-tipped cutter.

PHOTO 7: Poor man's Fly Press (see sidebar).

FRONT PANELS

Labels and front panels can make a big difference to any project. While the Dymo label may be authentic, these days, with computers everywhere, I find it easy to produce computer-printed labels and decals. Good software is the

PHOTO 8: An example of a computer-printed label with Lexan overlay.

starting point. I use and recommend Corel Draw, which is available in older versions—i.e., V8—for around $20, through many computer and stationery shops. I have used many methods over time; the simplest is to print your layout on photo-quality gloss paper and either have it laminated or protect it with a sheet of 1mm thick Lexan or acrylic

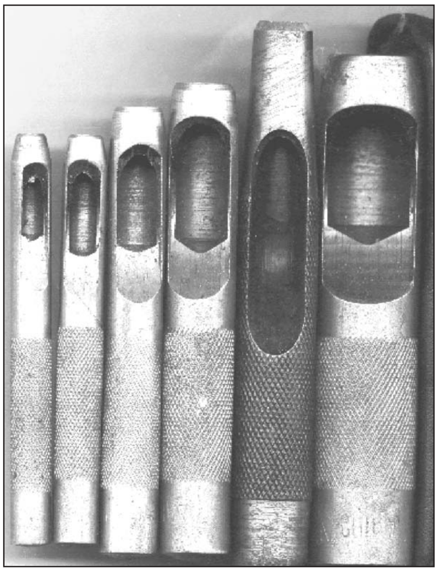

PHOTO 9: A selection of wad punches.

sheet. An example of a panel made in this manner is shown on my Stacker audio dummy load (*Photo 8*).

Wad punches (*Photo 9*) provide a clean method to make holes. These are frequently used in leather working, and are readily available in a variety of sizes. Always punch your holes using a piece of scrap timber, punching into the end grain. This will give a clean hole without any burrs.

You can also use a screen printing kit such as the Print Gocco (*Photo 10*), made in Japan, to screen-print professional labels directly onto a powder-coated chassis or front panel. An inexpensive front panel that I use is Laminex, glued to a metal backing. Laminex is available in a wide range of colors and textures, including a brushed aluminum and brass finish. The material is stable and can be easily screen-printed.

PHOTO 10: Print Gocco screen printing kit.

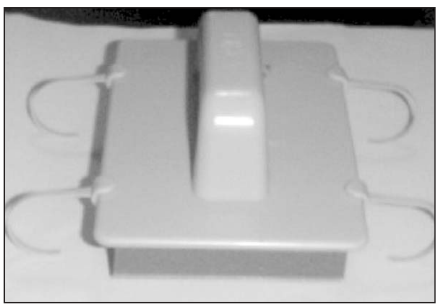

PHOTO 11: Print Gocco hand-held printing frame.

The screen printing method is easy to do and involves only a few steps. First, expose the silk screen to the original artwork using the supplied light box. The black areas of print on the artwork will allow ink to pass through the screen, thus making a positive print. Place ink on the screen, which goes into the printing frame, and then print the panels.

For large panels, a hand-held frame is available (*Photo 11*). Print size for the small kit is B3. A larger A4 kit is also available.

With the advances in printing technology, you can purchase used flat-bed plotters for a song from eBay. These are most useful to plot directly onto front panel material, or by using a modified pen, to plot resist directly onto copper printed circuit board. Another associate has also, with some success, used a plotter with a swivel cutter to make vinyl stick-on lettering for front panels. ❖

THE POOR MAN'S FLY PRESS

BY JIM TREGELLAS

One of my favorite tricks is a method which evolved for quickly producing burr-free circular holes in 16-gauge or thinner aluminum sheet. The principle is very simple: drill a piece of black steel plate about 3mm thick, using a drill of the diameter you want the hole to be in the aluminum plate. This becomes a die. Now reverse the drill in the chuck of the drill press so that the shank end of the drill faces the drill table (*Photo 7*).

Clamp the black steel plate to the drill table and adjust the table position so that the drill shank is centered in the hole drilled in the 3mm plate. Now put the aluminum plate on top of the steel plate, and abruptly lower the punch using the drill press handle. Result: a beautiful burr-free hole.

Refinements include adding locating surfaces to the 3mm plate so that successive pieces of aluminum end up with holes in exactly the same position, and flat-grinding the very end of the drill shank to form a slight burr, and consequently punching a clearance hole in the aluminum. With my drill press (a rather solid one), I can punch holes up to 9mm diameter in 1mm aluminum plate. However, once hole sizes go above about 5mm diameter, the end of the drill shank should be ground to form a very shallow V rather than a flat, to reduce the pressing forces involved.

I have used this technique regularly in semi-mass-production of metalwork for small-run items such as power supplies, and so on. If the steel base plate is accurately marked out and drilled, the method allows the quick manufacture of accurate front panels, and other parts, and, more important, provides clean holes for the mounting of power transistors with silicone rubber washers or micas. It is also very cheap tooling which you can quickly make at home.

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Product Review

DacT CT 100 RIAA Preamp

Reviewed by Charles Hansen and John and Sandra Schubel

Danish Audio ConnecT, Danish Audio ConnecT A/S, Skannerupvej 14, DK-6980 Tim, Denmark, Fax (+1) 248 282 0645, www.dact.com, dimensions: 10cm W × 9cm D × 4cm H.

The CT 100 is a dual-mono RIAA phono preamplifier circuit board, with both balanced and unbalanced line output capabilities. Each of the independent preamp sections has its own 3-pin power-supply connector (*Photo 1*). The board is 105mm × 63mm. An integral metal RF shield underneath the PC board increases the preamp length to 125mm and provides three mounting holes. The complete assembly is 35mm high at the tallest components.

The 8-page manual I received with the CT 100 is labeled "NLE 17 RIAA Amplifier," but the diagram of the circuit card is that of the CT 100. The manual is detailed and thorough. The finished board has no chassis, and requires a separate power supply or batteries. I used the DacT CT 102 power-supply board, which I reviewed in Oct '03 *aX* as part of a low-noise power-supply test. A "connector plate" fitted with two 3-pin XLR connectors is available for installing the CT 100 into a turntable, and detailed directions for such an installation are provided in the manual.

I mounted both PC boards in an aluminum project box (*Photo 2*), with gold unbalanced phono jacks and a chassis ground terminal to accommodate the turntable ground wire. I used shielded input and output connections of the shortest possible length to minimize noise.

Parts quality on the multi-layer PC board is first-rate, with polypropylene caps, surface-mount metal film resistors, and gold-plated PC board tracks. There are gold-plated male fast-on terminal blades for the input-output connections. As with the CT 102, there are a number of 8-pin DIP ICs whose identities have been hidden by white, red, or green paint. In the event of problems, you would need to send the CT 100 back to DacT for service.

The CT 100 can use supply voltages from ±9 to ±35V DC, with an absolute maximum of ±50V without damage. The maximum input voltage is ±1V. The input load and gain can be customized by use of four DIP switches (two per channel). The input resistance has 21 steps: 10, 15, 18, 20, 25, 30, 40, 50, 60, 70, 80, 90, 100, 150, 180, 200, 400, 600Ω, 1k, and 47k.

Given the wide range of low resistances available, you would expect to use the CT 100 with either moving coil or moving magnet cartridges, and this is indeed the case. You can select gains from 40dB to 80dB at 1kHz in 34 steps. If need be, you can make channel balance adjustments as well. The input capacitance is also switch selectable for 100, 200, 300, or 400pF.

The CT 100 is designed with a transistor-buffered low line-level output impedance that also allows you to drive many high-quality headphones. Finally, you can activate the RIAA 7950µS (20Hz) and/or 3.18µS (50kHz) rolloff time constants by means of two of the gain DIP switches[1]. Two input bias current trimpots are set at the factory and their adjustments are sealed.

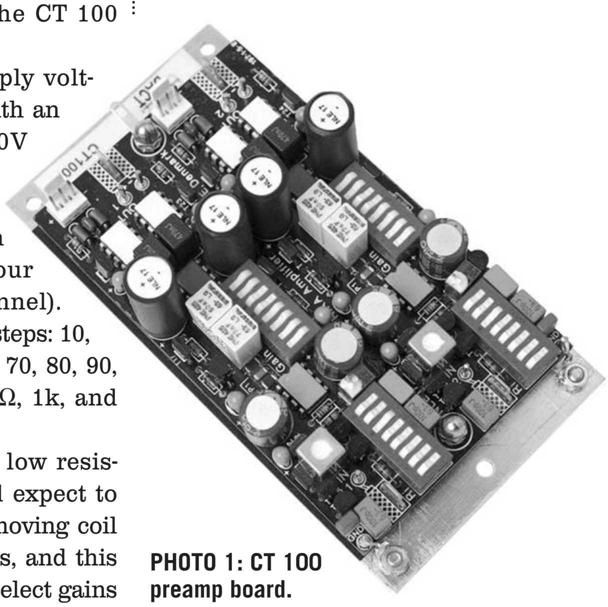

PHOTO 1: CT 100 preamp board.

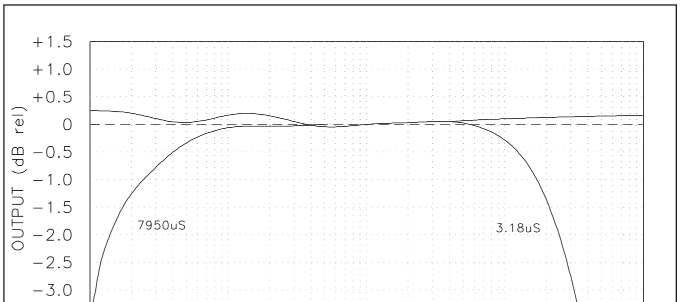

FIGURE 1: RIAA equalization error.

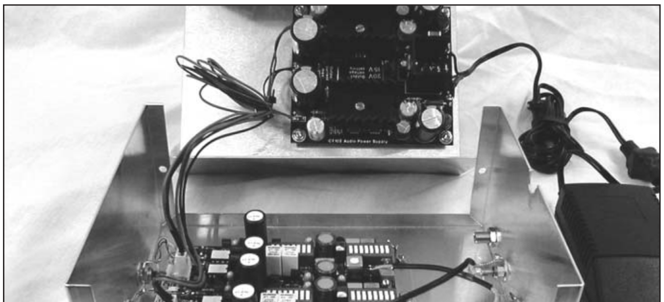

PHOTO 2: CT 100 preamp and CT 102 power supply in test chassis.

MEASUREMENTS

I set the CT 100 DIP switches as follows: 47k Rin, 100pF Cin, 40dB (MM) gain, and flattest response. I preconditioned the CT 100 at 2V RMS output, 1kHz for one hour. The line-level output load for all tests was 10k0. The left channel distortion measured 0.034% and the right channel was a bit higher at 0.038%. I subsequently used the right channel for the remaining measurements. A comparison of the DacT specifications (which are much more extensive than those listed here) and my measurements are shown in *Table 1*.

I used an inverse RIAA network (MM levels) for frequency response and the low-level distortion measurements. I measured the response and distortion vs. frequency with a test signal level into the inverse RIAA network that produces 10mV at 1kHz at the preamp input jack. This is equivalent to a cartridge with an output of 10mV at 5cm/s recording velocity (2mV/cm/s sensitivity). Typical vinyl records are recorded at 5cm/s maximum, while the RIAA specification allows a maximum recording velocity of 25cm/s (50mV at 1kHz for my testing). The RIAA specification requires that phono preamp THD+N remains below 1% with an input of 50mV at 1kHz.

The CT 100 maintains normal output polarity. The input impedance was 47k5. The output impedance was a low 31Ω at 20Hz and 1kHz, and 27Ω at 20kHz.

For S/N and DC offset measurements, I terminated the preamplifier input jacks with a "cartridge" load consisting of a 1k33 metal film resistor mounted in a shielded phono plug. The wideband output noise was 0.19mV left and right (–80dB). The initial DC offset voltage of –5mV settled to a wavering ±0.3mV.

The phono circuitry uses a DC servo to minimize the output offset, but whatever offset remains can be amplified by a DC-coupled power amplifier to values large enough to activate the speaker protection circuit. Crosstalk at 10kHz was a low –85dB. The A-weighted S/N ratio was –95dB relative to 2V RMS.

Figure 1 shows the relative RIAA equalization error (solid line), where 1kHz is the 0dB point. Gain at 1kHz, 10mV MM input, was exactly 40dB. Setting the DIP switches at the highest (MC) setting produced 80dB gain. The RIAA accuracy was within +0.2/–0.04dB from 10Hz to 20kHz. The two channels varied from each other by a maximum of 0.11dB at 125Hz, and less than 0.04dB over the rest of the curve.

I also plotted the response with the optional 7950µS and 3.18µS time constants engaged. The 7950µS high-pass filter also removes the slight hunting of the DC servo circuit, so it probably uses a series capacitor.

Figure 2 shows THD+N vs. frequency at a reference input level of 2mV/cm/s. I used the distortion test set 80kHz low-pass filter to limit out-of-band noise during the distortion tests. There is a dip in the THD curve at 60Hz, indicating the presence of some 60Hz hum pickup in my test setup. (The CT 102 does not bring 60Hz on board.)

I tried various ground connections between the distortion test set, the inverse RIAA network housing, and the preamp chassis, and the one that met with the least hum is shown in the figure. When I engaged the distortion test set 400Hz HP filter, the THD+N dropped to 0.016% above 2kHz.

For distortion vs. output voltage at 1kHz and 20kHz, I fed the sine-wave generator directly into the phono preamp without the interposing inverse RIAA network. The THD+N vs. line output level at 1kHz is shown in *Fig. 3*. The input overload at 1% THD clipping for a

TABLE 1: SPECIFICATIONS AND MEASUREMENTS, DACT CT 100

PARAMETER	SPECIFICATION	MEASUREMENT
MM Input Sensitivity, 1kHz	10mVin, 1Vout (40dB)	10mVin, 997mVout
Input Overload,		
20Hz		10.4mVrms
1kHz	100mVrms	95mVrms
20kHz		825mVrms
Gain, 1kHz, MM	40dB	40dB
MC	80dB	80dB
Input R,C	10Ω-47k0, 100-400pF	See text
RIAA Accuracy	±0.05dB	+0.2/–0.04dB
Output (unbalanced, 10k load)	±14.2V	13.8Vp-p (9.77Vrms)
Output Resistance	0.1Ω (Vo=1V)	31Ω (27Ω 20kHz)
Distortion, 1kHz 2Vrms	0.0003%	0.038% (see text)
Power Supply Rejection	120dB (Av=40dB)	
S/N, A-Wtd, Ref 5mVin	98dB	95dB
Crosstalk, 10kHz (Av=40dB)	–120dB (dual supply)	–85dB

10mV MM cartridge was quite generous: 10.4mV at 20Hz, 95mV at 1kHz, and 825mV at 20kHz. The ±15V DC supply rails provided by the CT 102 power-supply board limit the output voltage swing to 9.77V RMS. Again, the low-level THD+N noise was dominated by the unavoidable 60Hz hum component of my test setup.

The distortion waveform for 2V RMS into 10k at 1kHz is shown in *Fig. 4*. The upper waveform is the amplifier output signal, and the lower waveform is the monitor output (after the THD test set notch filter), not to scale. This distortion residual signal shows mainly the second harmonic, with some high-frequency noise.

The spectrum of a 50Hz sine wave at 2V RMS into 10k is shown in *Fig. 5*, from 0 to 1.3kHz. The THD+N measured 0.029%, and the few harmonics present are all below –95dB. The calculated THD based on the first five 50Hz harmonics is 0.0022%. The higher level spikes are all odd harmonics of the 60Hz power line frequency. The highest is 60Hz at –68dB, with the 180Hz harmonic at –79dB.

Expanding the spectrum analyzer horizontal scale to 40kHz (*Fig. 6*) shows the presence of the CT 102 power-supply switching frequency at –50dB at about 38kHz. While the gain of the RIAA preamp falls off at high frequency, the power-supply rejection ratio also decreases at –6dB per octave.

The 1kHz square wave with the flattest RIAA response setting (*Fig. 7*) is just about perfect, as are the 40Hz and 10kHz square waves (not shown).

REFERENCE

1. The fourth RIAA time constant of 7950µS is defined in IEC Publication #98, Amendment 4, dated September 1976. The fifth 3.18µS time constant is based on the Neumann cutting lathe amplifier manual; see "On Reference RIAA Networks," Jim Hagerman, *Audio Electronics* 2/99, pp. 10-13.

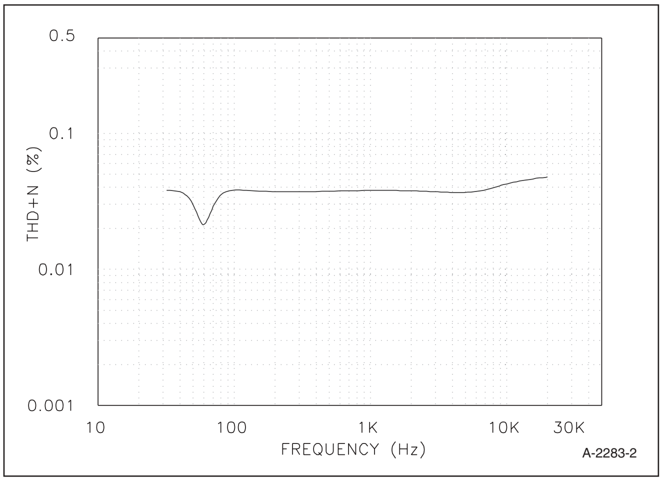

FIGURE 2: THD+N vs. frequency.

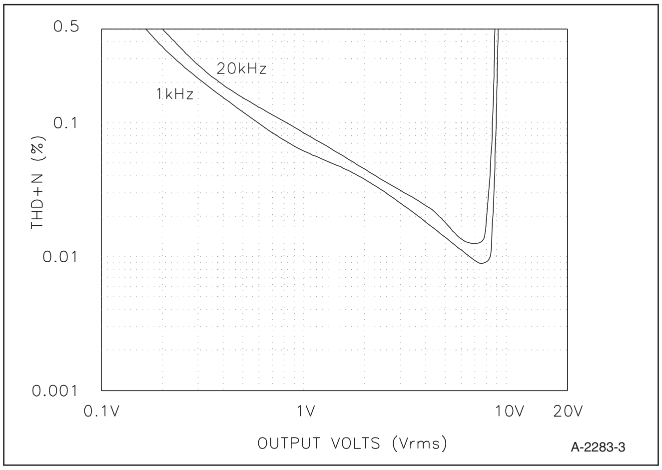

FIGURE 3: THD+N vs. line output voltage.

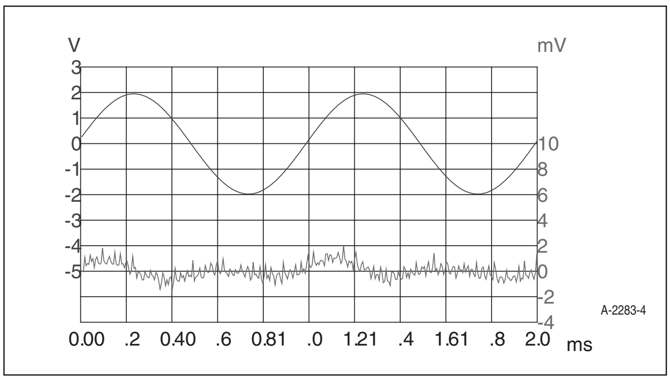

FIGURE 4: 1kHz residual distortion.

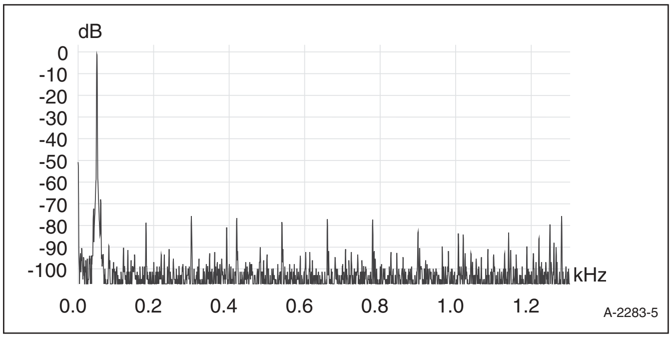

FIGURE 5: Spectrum of 50Hz sine wave.

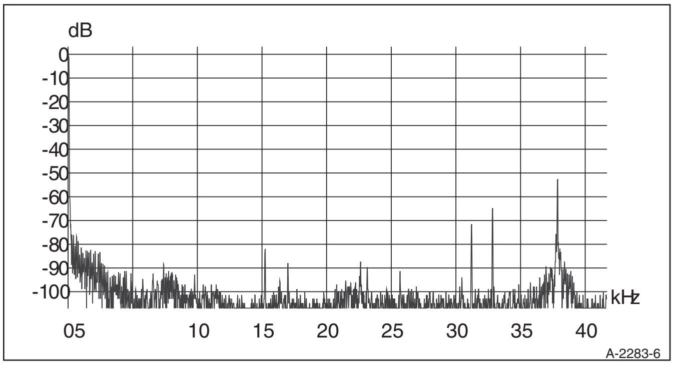

FIGURE 6: Spectrum of 50Hz sine wave, expanded scale.

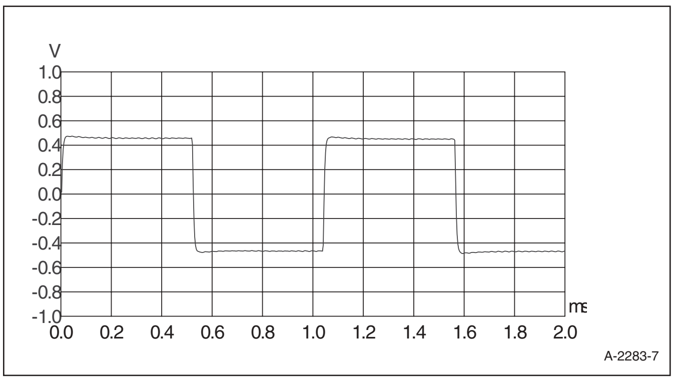

FIGURE 7: 1kHz square wave.

LISTENING CRITIQUE
DANISH AUDIO CONNECT DACT CT100 PHONO PREAMPLIFIER

By John and Sandra Schubel

We used Charles Hansen's listening room as the venue for the evaluation of the DacT CT100 Phono Preamplifier powered by a DacT CT102 power supply. The listening room is equipped with a Parasound HCA-1000A power amplifier driving NHT Super One speakers and a powered NHT SW2 subwoofer, and included two turntables: a Thorens TD 295 Mk III equipped with an Ortofon OMB 10 cartridge, and a Music Hall MMF-2 equipped with a Shure V15 type V cartridge. We used a passive preamplifier at the output of the CT100 to set listening levels, as well as the record selections previously used in the "Budget Phono Preamp Test" (*audioXpress*, April 2003, pp. 40–56).

We started out with the Moldau (Smetana), RCA Red Seal LSC-2471. The sound seemed distant and distorted. My [John's] first concern was that the record had experienced excess wear from the numerous playings required in the budget phono preamp review.

We tested this hypothesis by changing the CT100 for Charles Hansen's phono preamp (*Audio Electronics* 6/97, pp. 8–21), and again played the Moldau. The fuzziness was now gone. The culprit appeared to be the preamp, not the recording.

INSTRUMENTS

Next, we decided to use the Hagerman Bugle preamplifier that was the standout in the "Budget Phono Preamp Test" as a reference preamplifier for the evaluation of the CT100. I again used the Radio Shack sound pressure meter to assure consistency of levels. It quickly became apparent that the gain of the CT100 at 1kHz was very close to that of the Hagerman Bugle. We also noted that the CT100/CT102 combination background noise was as quiet as the Bugle with its two 9V batteries.

We again played the Moldau. The treble ranges sounded clear and crisp, particularly the triangles, but the bass was "blurry." I noted that the midrange had a distant, gritty sound. In general the sound was dry and distant.

When compared to the Hagerman Bugle, the instruments were not as well defined and the listener was placed further back from the sound stage. The placement of instruments across the sound stage was not as accurate. Interestingly, the CT100 handled crescendos better than the Hagerman.

We next turned our attention to "America" as recorded on "Lincoln Mayorga & Distinguished Colleagues Volume III, Sheffield Labs SL5/SL6." The CT100's sound on this cut is bright, but again the listener is distant from the sound stage. The bass on this cut was solid but gritty, and now the treble range, particularly the glockenspiel, sounded muddy. Similarly, the blocks and vibes sounded distant. The staging of the instruments was not all that clear, the instruments were not well defined, and the guitar, in particular, seemed lost in the soundstage.

We next listened to "That Certain Feeling," also on Sheffield Labs SL5/SL6. In comparison with the Hagerman Bugle, there was a lack of "snap" to the chimes, although the sound was generally brighter. The saxophone was gritty, and the trumpets very bright. The sound of the kick drum was solid, but the sound of the congas lacked richness. Both Sandra and Charles agreed that there was a lack of clarity in both sound and in placement of the trombone and brass.

We next challenged the CT100 with "Scheherazade" (Rimsky-Korsakov) as recorded by Leopold Stokowski and the London Symphony Orchestra, London SPC 21005. The horn entrance at the beginning of the piece was unpleasantly bright, with a kazoo-like sound. The violins lacked warmth. The harp, however, sounded clear.

As the piece progressed, the violin solo was very clear. In other sections of the piece, however, the violins sounded strident, with too much emphasis over other instruments. As the violins modulated upward, they retained the same balance with respect to other instruments, but were just too loud. The bass was again solid but fuzzy. The sound of the cello was dry, possessing no richness of tone.

The clarinets and flutes sounded natural on this recording. There was not as much definition between these instruments, however, as we would have liked. Placement of the instruments on the sound stage was again vague. Sandra noted that the piece was not interesting to listen to on this preamplifier.

VOICES

Our final listening selections were "Surely He has Borne our Griefs" and "All We Like Sheep Have Gone Astray" from Handel's "Messiah" recorded by Christopher Hogwood and the Academy of Ancient Music, and the Choir of Christ Church Cathedral, Oxford(L'oiseau-Lyre D189D3).

Our first observation was that the violins were again shrill, with much more presence and overtones than experienced with the more neutral-sounding Hagerman Bugle. In general the choir sounded brighter, with more emphasis on the treble voices. The bass voices were still there, but sounded less musical. When the choir sings forte, the sound becomes raspy.

In general the quality of the voices was less pleasing, perhaps due to the emphasis of higher frequency overtones. Sandra found the sound of the choir to be tiring. She thought that the breathing was softer, and that there was no boy-choir ringing sound. She found the sound of the choir to be generally less interesting.

We did not believe that we had good seats in the hall, although there was a general brightness to the sound. We could pick out the harpsichord more easily than with the Hagerman Bugle, although it was very quiet compared to the voices. The organ also seemed to stand out with more clarity.

By comparison, when we listened to this performance using the Hagerman Bugle, we sensed we were just three rows back. Using the CT100 cartridge loading DIP switches to remove all the capacitive loading (the Bugle has no loading capacitors at all) did not appreciatively alter the results.

The conclusion that we all reached was that this preamplifier produced a sound that lacked clarity, and seemed to be a bit excessive in the treble ranges. In general, the sound produced was tiring to listen to. Charles, in particular, was surprised by the sound of this preamp, as it produced excellent measurement numbers, with only +0.1dB response error at 10kHz. This listening experience reinforced to us the importance of auditioning audio equipment rather than just examining the numbers.

Manufacturer's response:

First we would like to thank audioXpress *for taking time to test our products and for allowing space in the magazine for the review and for our following comments.*

However, we do regret that audioXpress' *policies have made it impossible to enter into a dialogue regarding the results of the review. Not only are some of the measurements in the review so far from DACT's published specifications that we would have expected the reviewer to become suspicious something was wrong, and contacted us to discuss the situation. But also the listening tests show so severe problems that again, we would have expected to have been contacted and asked if something might be wrong. The listening impressions stated in the review are far from what you would expect from high quality audio highly acclaimed by other sources. We refer to the review section at www.DACT.com.*

After having read the review draft we did re-check the very same CT100/CT102 combination that was used for the review. Powered by the review of the CT102, we have performed various measurements on the CT100 review unit. We have again verified our own specifications: the unit meets the data that we publish under the measurement conditions given for practical use.

THE SOUND

It is said in the review that the listening test is a very important part of an evaluation of an audio product. We could not agree more. However, the sound character of CT100 that the review spells out is so far from everybody else's experiences that we can hardly believe it is the same product. This is not only supported by our own years of listening to CT100 but also by customer feedback and other reviews that CT100 has received.

Without having been given the opportunity to discuss with the reviewer, we are left with trying to guess what might have happened.

First of all, it appears that the input settings (gain, capacitance, and resistance) were set once and for all, and never tried reset to check if other settings obtained a better match for the specific cartridges. If the cartridge manufacturer's recommended settings were used, it might have been the right settings, although this is not always the case. If the settings were less well considered, certainly this could cause less than optimal sound reproduction.

More importantly however, we worry about the "passive preamplifier" that was used for the listening tests. DACT has a decade of experience in manufacturing high quality stepped attenuators and we know very well about the potential problems of passive preamps. At www.DACT.com we even publish an article about passive preamps.

The listening part of the review was carried out so the passive preamplifier was connected at the output of the CT100 phono stage for adjusting its volume. The review is not clear about whether the same passive preamplifier was used for the other phono stages used in the review for comparison. In any case, the review does not mention any details about this passive preamplifier: Based on the reported listening critique, we assume that the used passive preamplifier *comprised an ordinary carbon or conductive type potentiometer. We know that passive preamplifiers may cause similar sound characteristics as reported in the review—especially if the passive preamplifier is based on a poor quality volume control.*

MEASUREMENTS

Inverse RIAA network

Measuring a high precision phono stage using an inverse RIAA network requires the utmost attention and care. It is very important to make sure that the measurements carried out on the output of the inverse network show the performance of the Device Under Test (in this case the CT100 phono stage) rather than the performance of the inverse network or a combination of both. We would have found it very useful had the review included information about the inverse RIAA network used for the measurements, especially its inverse RIAA correction accuracy.

Instead of using inverse RIAA networks, we suggest simply measuring the output voltage of the phono stage as a function of frequency, and compare to the theoretically correct RIAA curve. This is the way DACT measures the correction curve, and each CT100 we ship has been checked and found to be within ±0.05dB of the correct curve. We have re-checked the review unit and found it to be within the specified ±0.05dB.

Without having been able to discuss with the reviewer, our conclusion on the measured RIAA curve accuracy is that it probably shows more about the (in)accuracy of the inverse RIAA network used for the measurements than it does about the CT100 RIAA correction.

Output impedance

There is a very significant deviation between the output impedance measurements referred to in the review (30Ω) and the figure we measure (0.1Ω).

Again we are left guessing what causes the difference and we suspect that the review figure is a result of overloading the CT100 output. CT100 features output current limitation of 25mA for protection purposes. If the output impedance is measured at overload conditions (specified load for measurements is 1kΩ), so the output devices of CT100 entered into their current limitation region, the output impedance would increase dramatically. We believe this is the reason why the review states a wrong output impedance of 30Ω.

Distortion

On the review unit we have re-tested THD and found it to be in accordance with our published specifications below –110dB at 1kHz.

At 50Hz, 2nd harmonic is –110dB and 3rd is –104dB and we have measured THD to be –101dB at 50Hz.

The CT100 provides ultra-low distortion to secure state-of-the-art sonic performance. This is a challenge to even today's test equipment capabilities concerning signal purity and low noise. DACT recommends as a minimum, that the test signal THD is below –126dB and the test analyzer signal noise level to be below –130dB for reliable results. DACT distortion measurements are obtained with such test equipment at the facilities in Denmark. Distortion measurements of CT100 according to audioXpress *test, Fig. 5, are not possible since no harmonics below or slightly above the noise level of –100dB can be detected and evaluated.*

We cannot confirm that the review THD can be concluded from Fig. 5 and it appears that audioXpress *was unable to measure harmonics below approximately –100dB.*

OUR CONCLUSION

It appears that a number of issues have caused this review to turn out very differently from what it normally would.

We find several of the measurements performed under less realistic conditions resulting in deviating results. We have checked the CT100 review unit again after the review and have been able to verify our specifications. None of the measurement results from the review have made us doubt the correct CT100 specifications that we publish.

As for the listening results, we also must conclude that the review does not give a rightful picture of what our CT100 phono stage stands for.

I wish we had been able to have a constructive dialogue with audioXpress *at an earlier stage to straighten out the misunderstandings. We feel that this lengthy response to the review is required for the* audioXpress *readers to evaluate this example of differences in opinion concerning listening and measuring.*

Allan Isaksen, DACT

Charles Hansen responds:

In instances where the listening results seem to have a large disconnect from the measured data, as was the case with the CT100, I try to determine the reason. If I happen to have a schematic available, I attempt to find where in the audio circuitry the observed anomaly has occurred (see "Budget Phono Preamps," audioXpress *April 03, pg. 44 sidebar "Solving for Instability"). This was not possible with the CT100 since I did not have a service schematic and could not even do any intuitive troubleshooting because the identities of all the IC packages were hidden by various colors of paint.*

There was some speculation by Allan Isaksen of DacT about the health of the CT102 power supply provided for the review (see audioXpress *Oct. 03, pp. 60-61). I made sure that the DC rails from the CT102 into the CT100 phono preamp were at their specified voltages and noise levels prior to any listening audition or measurements. The CT100 current draw is nowhere near the current limit fold-back point I measured during the CT102 tests.*

As mentioned in the CT100 review, two different turntable/cartridge setups were available, as well as two other active phono preamps. We tried all the combinations of capacitor dip switch settings on the CT100 in an effort to improve the sound, to no avail. The only resistive loading available for MM cartridges was 47k (the next value being an inappropriately low 1k). I did not take note of where the dip switches were left when I shipped the two units back to DacT. ❖

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Peterborough, NH 03458

CORRECTION

My deepest apologies to you all for letting this one slip by me! In Fig. 1 of my article "Mini SE Amp," (Apr. '04), resistor R7 should be connected to the ground (–) side of capacitor C5 instead of the positive (+) side. I sincerely hope that this error does not cause anyone any problems.

Rick Spencer
Clovis, Calif.

MCINTOSH MC2100

This is in reference to Bruce Brown's interesting makeover of the McIntosh MC2100 ("Rebuilding a Classic," Feb. '04 *aX*). On page 22 he mentions his matched 2N3772 output transistors as high voltage versions of the 2N3055.

I remember these devices very well when we were matching six ranges each of V_{BE} and h_{FE} for static inverters. This required a very expensive Tek 667 curve tracer with the power transistor high-current add-on. The 2N3772 is not a high voltage version of the 2N3055. They are different devices with different size die. After Bell Labs invented the diffused base process, the 2N3055 was one of the first single-diffused base transistors that RCA developed. It was rated 15A and 115W at a V_{CEO} of 60V, h_{FE} gain ran 20–70 at 4A, and the $f_{\alpha e}$ was 10kHz.

The 2N3772 came two years later. While it was also single-diffused, it was rated 20A continuous (30A peak), 150W and had the same V_{CEO} of 60V as the 2N3055. Gain was lower—15–40 at 10A—but it was a better switcher with a current gain-bandwidth f_T of 200kHz.

Little was known about the bipolar transistor secondary breakdown effect at the time, and many of these transistors were self-destructing in both switching and power amplifier applications. The 1960 RCA Transistor Manual has no safe operating area (SOA) curves at all. Motorola and Texas Instruments also made versions of these devices.

The author says his transistors are rated at 70V, but that is V_{CER}(sus), the sustaining voltage with no base drive, I_C = 200mA and R_{BE} = 100Ω. This was not an operating point, and it could not even be measured on a curve tracer without risking damage to the device. The first SOA curves began appearing in the transistor manuals in the mid-1970s.

Bell Labs developed the epitaxial process in 1960, and Motorola made the first production "Power Base" epi transistors in 1962. RCA and TI soon followed with their own epi "Hometaxial" and "EpiBase" devices. Motorola made the 2N3055A, an epi version of the 2N3055, in the late '70s/early '80s, with an improved f_T of 2.5MHz.

I may be wrong, but at this point I would think any new 2N3055 or 2N3772 would be an epi base device. The planar epi process has been refined by the integrated circuit industry and is less expensive than the single or triple diffusion process.

Charles Hansen
Ocean, N.J.

Bruce Brown responds:

I very much appreciate Mr. Hansen's information and comments. As usual, I have learned a great deal from the contributors of audioXpress. *I do not have access to the original documentation on the 2N3772 transistors, but will attempt to share the information I do have. In checking several cross-reference guides, there are several that cross-reference to audio outputs. Using the SK series guide, the 3772 crosses to a SK3036, which is listed as a high power output transistor for AF applications.*

Additionally, I have a Dynaco Service Update that states that the 2N3055A can be replaced by the 2N3772. I have used these transistors in ST-120s and ST and SCA 80s and have never experienced a failure. Recently my friend, mentioned in the original article, used them to replace the outputs in one side of his McIntosh 6100 integrated amp. He tells me that they run much cooler than the originals and "sound great." The 2100 I rebuilt for the article has several hundred hours on it and still sounds great.

USHER REVIEW

In his review of the Usher CP8871 (Feb '04 *aX*), James Moriyasu made some comments relating to the order of placement of R2 in the series LCR filter for the mid-range driver which don't make sense to me. He states:

". . . a resistor's placement in a crossover network can affect the shape of the network's transfer function—in particular, the damping at the "knee" of the transfer function." He quotes a reference 4 which I don't have as a means of checking the context of his statement. Further on he relates this statement to the ability of R2 to handle power dependent upon where it is placed in the series LCR network comprised of R2, C3, L4.

"The need to shape the transfer function might be the reason why R2 is at the front of the crossover network. The trade-off with this placement is power handling, because the resistor must bear the full bandwidth and power of the input signal. In general, I guess, placing a resistor after a capacitor would be preferable, because most loudspeaker capacitors are rated at 100V or more, and can presumably do a better job than a 15W resistor when it comes to handling power. Placing a resistor after an inductor would probably be preferable too, since the inductor would attenuate a portion of the input signal."

I don't know whether I am correct, but James seems to be assuming that by placing the resistor after the capacitor the impedance (presumably at low frequencies) of the capacitor will somehow minimize the power required to be handled by the resistor. Similarly, if placed after the inductor the resistor would also be required to handle less power (presumably at higher frequencies).

Unless there is something I don't know, the position which a resistor takes in a series LCR combination makes no difference whatsoever in its requirement to handle power. If you take the series LCR combination by itself, you know that it has some resonant frequency Fo where current through the series components will be maximum and thus the power handled by the resistor will also be maximum.

If you look at the capacitor by itself, you know that at low frequencies its impedance will be high and the current through all three components simultaneously will be determined mainly due to the impedance presented by this component alone. Therefore, at low frequencies, the power handled by the resistor will be low and it will be the same at any particular frequency no matter where it is placed in the series connection, either before or after the capacitor or inductor. As frequency rises, the impedance of the capacitor will fall and the current and therefore the power in the resistor will rise as frequency tends towards Fo.

Similarly, with the inductor, the impedance will be low at low frequencies and will increase as frequency increases. At higher frequencies the impedance of the series combination will be mainly due to the inductor. No matter where the resistor is placed in this series network the current will be the same at any particular frequency. Thus the power dissipated in the resistor will be the same irrespective of its position. As frequency rises beyond Fo, the impedance of the inductor continues to rise and the current and power in the resistor will fall.

If you were to conduct an experiment with a series LCR circuit, you would see that when swept over a range of frequencies, the shape of the resulting current function would be exactly the same no matter where the resistor was placed. Since current is related to power, the resistor would be required to handle the same power no matter where it is placed in the series network.

Perhaps I am missing something?

Ross Herbert
rherbert1@pop-server.bigpond.net.au

James Moriyasu responds:

My comments regarding the placement of the resistor in the Usher crossover refer to the one that is in series with the tweeter. The resistor in the conjugate or LCR is not part of the discussion, at all.

Again, the point being made is that putting a resistor in front of the capacitor exposes it to the full bandwidth of the signal and thus compromises the power handling of the resistor. As most know, a capacitor "blocks" or attenuates frequencies below a certain cutoff point, and thus the tweeter and the resistor in series with it has much less power to handle. Certainly, one reason for a tweeter crossover is to make sure the tweeter isn't burned out. The same goes for the resistor that is "padding" the tweeter down.

The second point being made is that most capacitors that are commonly available are rated at 100V or better, which, I think, is more than what a typical 15W resistor can handle. If my math is correct, 1W at 8Ω is 2.83V, while 16W at 8Ω is 11.32V. Still, I must confess that I've never conducted empirical tests to see how much power resistors and tweeters can take before they fail. It might be the basis for an interesting study and a subsequent article.

On the other hand, you could argue that resistors are cheaper than good capacitors, and it makes more sense to put a resistor with adequate power handling in front of the capacitor. This could be easily accomplished by doubling or quadrupling a lower rated resistor.

ARCING PREVENTION

Regarding recent reports of arcing of power tubes at high signal, there may be a simple prevention.

Some of the factory dust inside the tube is metallic. Over time, the combination of high positive voltage swings and acoustic vibrations happening simultaneously (you headbangers) will migrate the dust sitting on the mica discs to the locations of highest peak electrostatic field: I believe between the plate and the suppressor. The forming dust chain gradually reduces the vacuum gap and acts like a lightning rod to encourage an arc. I was lucky enough to be actually looking (it's beautiful) during two recent arcings which blew my 800mA HT fuse.

The treatment is simple: hold each power tube horizontal and tap it vigorously with your fingernail. You will see dust fall to the glass! Rotate slowly about the long axis while tapping to free it all. Then slowly tilt towards upright while continuously tapping to get all of the dust down into the base out of harm's way. With 3.75D "close-work" spectacles I could see it moving very clearly. (Of course, transistor manufacturers had to go dust-free).

So far I have had no more blowups during headbanging sessions, which is good because that second arc turned that tube into an incurable runaway—i.e., gradually glows red-hot a few minutes after switch-on due to escalating positive ion current to the control grid—very nasty, with potential fire hazard if you're not handy. (And I had to reselect eight new power tubes for current balance.)

Jim Carlyle
New Zealand

TWEETER REPLACEMENT

In regards to the DR5 horn speaker article by Bill Fitzmaurice (July '03 *aX*, p. 10) Parts Express no longer sells the CTS model KSN1036 tweeter. I would greatly appreciate if you could recommend a replacement for this tweeter, even if it costs more. Thanks!

John Kohls
kohlsjohnw@johndeere.com

Bill Fitzmaurice responds:

I pulled a tweeter on one of my DR5s and measured the clearance from the face of the tweeter baffle to the woofer magnet at a bit over 2″. That being the case, the CTS KSN1038a will fit. It has a 3¾″ round face-

plate, the same as the KSN1036a, which as noted in the article will require some sanding to fit.

TWO-WAY ENCLOSURE

My interest is in any additional info you could provide for the version of system #2 you built, including the Vifa silk dome tweeter. Your comment about building it yourself with good results caught my eye. I'm considering a 2-way with that tweeter for my rear-channel home theater setup. I've completed the ME 2 of Lynn Olson's design for front channel.

Thank you for your article. I appreciate your sharing with us such things that help us understand better.
Ed LaFontaine
Berea, Ky.

G.R. Koonce responds:

I want to thank Mr. LaFontaine for his interest in my article "Why Speakers Have Sloped Front Panels" (Dec. '03–March '04 aX*) and his question regarding example speaker system Sys119. This system used the Vifa D27TG-35-06 silk dome tweeter and the Carbonneau #24882 8″ woofer, drivers of unknown current availability.*

Part 4 of my article points out that this system was constructed as a floor-standing enclosure with the tweeter mounted below the woofer to convert the vertical beam angle (VBA) to +8°. With the tweeter about 6″ off the floor, the indicated front panel tip angle was in the range of 10°. The final enclosures used a 12° tip angle.

A full article would be required to document the construction details for these systems. I don't believe such detail would be of real value to Mr. LaFontaine for his intended application as home theater rear-channel speakers because:

1. *The Sys119 systems were constructed as infinite boxes[1] with full diffraction spreading loss (DSL) compensation for sitting away from the walls. I would expect rear-channel speakers to sit close to the wall. The construction used was basically as covered in Part 2 of reference 1 for other infinite box systems.*
2. *The 8″ woofer two-way system is one of the toughest crossover design problems in this speaker hobby. The difficulty is in obtaining a smooth, believable midrange response. About a dozen crossover designs*

were developed and listened to before I was happy. I don't recommend going to an 8″ woofer in a two-way unless you really need to.

3. *Normally the frequency content to the rear-channel speakers is limited to somewhere in the range of 80 to 120Hz on the bass end. This can be accomplished with a smaller woofer, meaning an easier design and smaller enclosure. Perhaps some of the speaker projects developed or proposed in reference 2 would be better candidates.*

If Mr. LaFontaine really wants to use the drivers of Sys119, I recommend he use a closed-box design for the woofer to remove some of the DSL compensation. As long as he uses a floor-standing enclosure with the tweeter about 6″ off the floor, a 6.5″ CTC vertical spacing between the tweeter and the woofer above it, and a front panel tip angle in the 10–12° range, the crossover design shown in the article should work fine. The tweeters were offset 1″ from the woofer vertical centerline in mirror-image fashion.

Note the crossover design is based on both the woofer and tweeter being surface-mounted with a diffraction ring used on the tweeter. See reference 2, page 172, for development of the diffraction ring concept and how to use them. Reference 3 shows how to build the rings for a specific project.

These enclosures would be rather large for stand mounting, but this could be done by following the information in the article using a VBA of –8° if the tweeter is mounted at the top, and +8° if it is mounted below the woofer.

I hope this reply gives Mr. LaFontaine the information he was seeking.

REFERENCES

1. Koonce, G. R. and Wright, Jr., R. O., "The Infinite Box Concept," *aX*, January 2002, p. 8, and February 2002, p. 38.

2. David B. Weems and G. R. Koonce, *Great Sound Stereo Speaker Manual — Second Edition*, McGraw-Hill, New York, 2000.

3. Koonce, G. R., "A Pair of Computer Speaker System Designs, Part 1," *aX*, April 2001, p. 31.

SOURCES

I would like to try Gary Galo's Adcom GFP-565 preamp mod (Nov. and Dec. '03, Jan. and Feb. '04 *aX*), and I am ready to order all the parts, except I cannot find a source for the AD745. Rochester will not even respond to my e-mails. Is there a suitable substitute for the AD745?

Chet Staley
cstaley12@attbi.com

Gary Galo responds:

There is no substitute for the AD745. Before giving up on Rochester Electronics, I would try calling them using the phone number listed on page 37 of Part 4. If you still don't have any luck with Rochester Electronics, you can buy the AD745JR-16 directly from Analog Devices at www.analog.com. Use it with the Aries SOIC to DIP adapter, as described in the article.

LOW-COST VT AMPS

Congratulations to Richard Spencer for an excellent article on the low-cost 12L6 single-ended stereo amplifier (April '04). Your articles are truly superlative in establishing contact with the audiophile that needs a little push to become a homebuilder. This article, as well as your previous articles, are very well thought out technically and are very conservatively designed. The writing is very descriptive and insightful. I want to thank you again for presenting to the readers a vacuum tube stereo amplifier that can be built for less than $200. A job well done. I look forward to more of your interesting articles.

Joseph Norwood Still
Bel Air, Md.

AUDIO FIX

Just got the April 2004 issue today—wow! What a great set of articles. "A Mini SE Amp" is just what I was looking for. Since I believe I'm the one Mr. Spencer refers to in the introduction, I guess I have no choice but to build one. The "Tube Audio Construction Tips" article sure goes right along with it.

I was disappointed to see the Alesis ML-9600 review, though—I've been trying to restrain myself from buying one, and you guys aren't helping one little bit. Did someone say "tax refund?"

I also enjoyed the review of Walt Jung's book. I'd buy anything Jung writes, sight-unseen, but it was nice to see what I'll be getting. As a working EE (over 20 years now), I have the predictable shelves of op amp books, some quite good, but none with the breadth/depth to be the "final" op amp book. This may be it.

Finally, Bert Fruitema's "Showcase" Dutch tube amp—what can I say? I know color costs, but you need to splurge for occasions like this. The cover pictures were nice, but small, and no front view! I'm not being critical, really, I know you have a lot of constraints. That amp has better aesthetics than most tera$ commercial products.

Doug Burkett
dburkett@infinet.com

HELP WANTED

Can you possibly assist me in finding a source for a new transport for a POOGE-4 Magnavox CDB460? I would hate to abandon the machine, as it sounds so sweet, but the transport now needs replacement. Any ideas would be greatly appreciated.

John Birrell
hubris2@earthlink.net

James C. New is interested in building a stereo AM tuner, with possibly a digital readout, but he needs help and collaboration. If you are interested in helping, his address is
1285 Starpass Dr.
Jacksonville, FL 32256.

I would like info on true ribbon tweeter transformers. A true ribbon has a matching transformer, which obviously is very small, with limited range 1K-20-30kHz. I have never seen them offered to the hobbyist speaker builder. They must match a very low resistive ribbon diaphragm to an amplifier. Please give me some info on these devices.

Mark
mccaslm@aol.com

Readers with information on these topics are encouraged to respond directly to the letter writers at the addresses provided.–Eds. ❖

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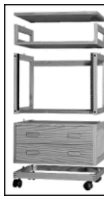

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AD INDEX

Audio Aid

High Current-Regulated Heater Supplies

By Michael Kornacker

In my article "Current-Regulated Supplies for Heaters Provides Better Stability" (Apr. '03 *audioXpress*, p. 72), I discussed how a current-regulated heater would be more appropriate because the heater seemed to be more of a current-operating device than a voltage-operating device. Also with current-regulated heaters comes the added benefit of exhibiting no turn-on current spike by keeping the in-rush current to the normal operating-current value, thus ensuring longer tube life.

I showed how to use the common LM317 three-terminal regulator configured as a current regulator. I noticed in my research, however, that I had never seen a circuit using the LM317 that could provide and regulate a higher current to a load than what the LM317 could deliver. In voltage-regulator circuits you can use a high power pass transistor that would provide more current to a load than what the voltage regulator could by itself.

I wanted a circuit that could perform current regulation but at a higher current level than what the LM317 could provide by itself. *Figure 1* shows my circuit solution that uses a 2N3055 high power pass transistor in the same way as the high current voltage-regulator circuit, but the pass transistor's base is driven with the LM317 in a current-regulator configuration. Another benefit of this circuit is that you can easily obtain the parts at Radio Shack.

By utilizing the pass transistor's beta or hfe, I can control a large load current flow through the collector by way of a small, regulated current applied to the base. And since the base current flow will be regulated, then the collector current flow will also be regulated so that any load such as a high current heater could experience the benefits of current regulation.

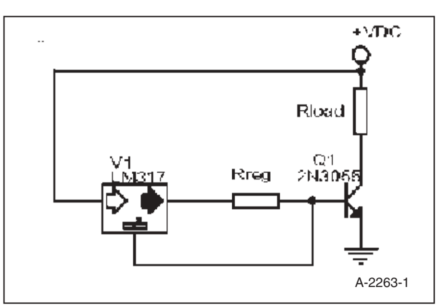

FIGURE 1: Current-regulation circuit.

HOW THE CIRCUIT WORKS

Figure 1 uses a typical 2N3055 bipolar power transistor as a pass element Q1. Rload represents the high current heaters of a set of tubes. The voltage supply +VDC is the voltage at which the tubes need to operate—plus a little more because Q1 is going to inherently drop some voltage across the collector-emitter junction. The voltage supply could be voltage regulated if you choose.

Connected from the power supply to the Q1 base is U1, a typical LM317 current-regulator circuit configuration in which Rreg sets the current supply coming out of U1. It's as simple as that. Next comes the hard part: figuring out what Rreg needs to be to make the circuit regulate the current. I found that the following calculations will help, but in the end, unfortunately, you'll need to rely on the cut and try method to get the exact value you need.

The equation for Rreg as stated for a LM317 current regulator is equal to 1.25 divided by Iout. Iout is the same as the Q1 base current, Ibase, which will drive Q1. The current flowing through Rload is really the same as the Q1 collector current, Icollector, also called Iload. The value called beta or hfe for Q1 is equal to Icollector divided by Ibase.

The manufacturer provides the value of hfe for a 2N3055, and Iload is the sum of the heater currents you wish to regulate. Therefore, Ibase (or Iout) is equal to Icollector (or Iload) divided by the hfe. Putting this all together:

Rreg = [1.25 / (Iload / hfe].

The value of hfe is not very exact. As a matter of fact, hfe for the 2N3055 is sometimes given as 20 to 70, which is not really precise and not much help, or is given as a value of a minimum of 20, which is even worse. Because hfe is so inexact, in this particular case, finding the right Rreg to regulate the load will take some experimentation. In the end, I found that Rreg turned out to be so far off that the previous equation only serves as a starting point.

I experimented with the circuit until I found the value that worked. The resistor I ended up using was about three times larger than what I calculated using an hfe of 70. I don't know about any other types of transistors, but I'd expect a wide variation between calculated and actual values for Rreg. No matter, though, the important idea is that it works.

I know the value of Rreg is correct in my circuit because when I turn the power on to the heaters, the current flow value goes directly to the normal operating value that I expect and not over it. Remember, in a typical, non-current regulated arrangement, when cold heaters are first turned on, they'll instantly draw many more times their normal value before the current settles down to a steady state.

That's the key. Select Rreg so the current flow value, as witnessed on a current meter, increases directly to and levels off at the normal operating value that you expect. If the current rises above and then decays to the steady current state, then you know it's not regulating correctly, so increase Rreg until it does. If you're not meeting the desired steady state current level at all, then decrease Rreg until it does.

Don't forget about heatsinking the pass transistor, since high current flow will cause it to generate heat. The LM317, however, should probably not need heatsinking because its current output should be quite low. ❖