

All FET Class-A 75W Amplifier

Starting life as a Borbely kit, this project goes a step further and utilizes an external power supply, normally associated with line-amps, headphone amps, and phono preamps.

By Rick MacDonald

While it is impractical (not to mention expensive) to power a Class A amp using batteries, it is, however, practical to build a separate power supply using umbilicals. Some of the benefits are obvious, but there are other reasons that some DIY builders may not have considered.

The idea for this project (**Photo 1**) began when I was listening to a headphone amp connected to a separate battery power supply. The sound of this amp was so quiet, with extended bass and very detailed mid and high frequencies, that I thought, "There must be a way to realize some of these benefits with an amplifier driving speakers, and not just any, but a full Class A amplifier." If I built this amp, it would need to be constructed from the beginning this way, and not just as an afterthought to solve problems with hum or other noise caused by transformers and their stray magnetic fields. It would need heavy well-made umbilical cables with connectors that are up to the task. With these things in mind, I decided to use a tested design for the amp and power supply, which brought me to the Borbely 75W Millennium.

DESIGN OVERVIEW

The basis for this amp comes from Erno Borbely's All FET Class A Millennium Amp (borbelyaudio.com). Intended to be built as two monoblocks, it can also be constructed as either stereo or dual mono, which is how I chose to build it (**Fig. 1**). With an array of ways to purchase it (you can buy the full kit, just the PCB, or almost anything in-between), I went with the PCBs and the semiconductors only; used my own sources for resistors, caps, and transformers; and also built my own

enclosures. The amp consists of one driver board, one output board, and one power-supply board per channel. You can save yourself a lot of hunting for parts by ordering the entire kit, but if you are determined, I recommend getting the semis, as some may be tough to source, particularly the matched FETs.

The driver is an all-FET high-speed circuit with onboard regulators. Maximum supply voltage is $\pm 55V$ (unregulated) and is adjustable from 30–50V. The unit can deliver 100W, but only 75W in pure Class A. Fully complementary, the input stage is differential cascode, using dual monolithic JFETs as input devices and MOSFETs as cascodes.

DC offset is tracked/controlled by the AD820, a JFET op amp powered by a shunt regulated $\pm 10V$ supply. A relay out is provided

to avoid the small turn-on thump (I used the direct out also provided). To handle any overly capacitive speaker loads, I used an L1R1 parallel combination on the output to control oscil-

PHOTO1: Front view of the completed amp.

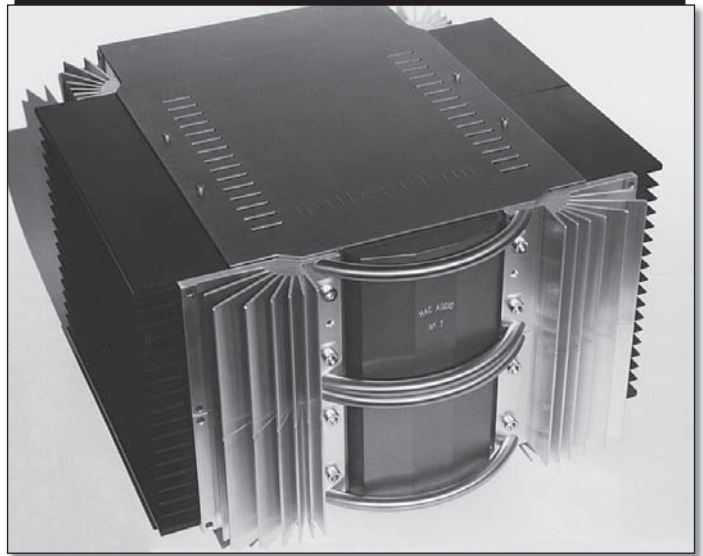
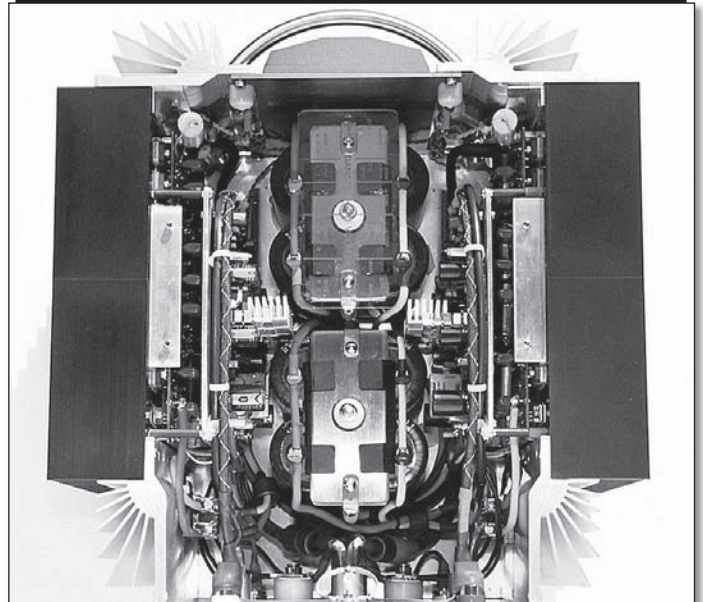


PHOTO 2: Top view of completed amp.



lations, but it is easily bypassed for lower damping.

The feedback network (called a T-network) was developed for the all-FET line of power amps. It accommodates both balanced and unbalanced operation, without changing the feedback network. A switch at the input equalizes gain in both modes, and ensures equal impedance for the two inputs.

The output stage uses eight pairs of TO-3P power MOSFETs (2SK1058/2SJ162), which come tested and matched, and this batch had the same lot code, which helps ensure good matching even with bias currents other than those used for the matching process. For this reason, no source resistors are required. The sole purpose of this circuit is to move huge amounts of current, and no voltage gain is introduced. These MOSFETs become very hot and must have significant heatsinking to run Class A.

As you can see in **Photo 1**, the enclosure provides just that . . . in abundance. The big horseshoe-shaped heat-sink (**Photo 2**) makes a good strong chassis. Vertical corner sinks supplement the horizontal fins of the main heatsink (black). For reasons of assembly and other design issues, it was the only way they would all fit together. Considering the enclosure was built using available parts, surplus heat-sinks, and scrap pile aluminum, it came out reasonably well.

The power supply is simple, consisting of independent supplies for driver and output stages and including delay timers for power-on and speaker relays. The main power caps are separate from the kits, and 100,000 μ F per rail is recommended. I used NTC thermistors on the power-supply board to reduce inrush current, and you can order transformers along with the kits. I used separate surplus transformers (for driver and output boards) on this project (625VA—minimum required).

WHY EXTERNAL POWER SUPPLY?

The most obvious benefits—reductions in noise, hum, and EMI—have been proven in line and headphone amps. AC

mains can bring in all kinds of garbage picked up along the way. Microwaves, RF, and switching power supplies all contribute to the hash that can cause

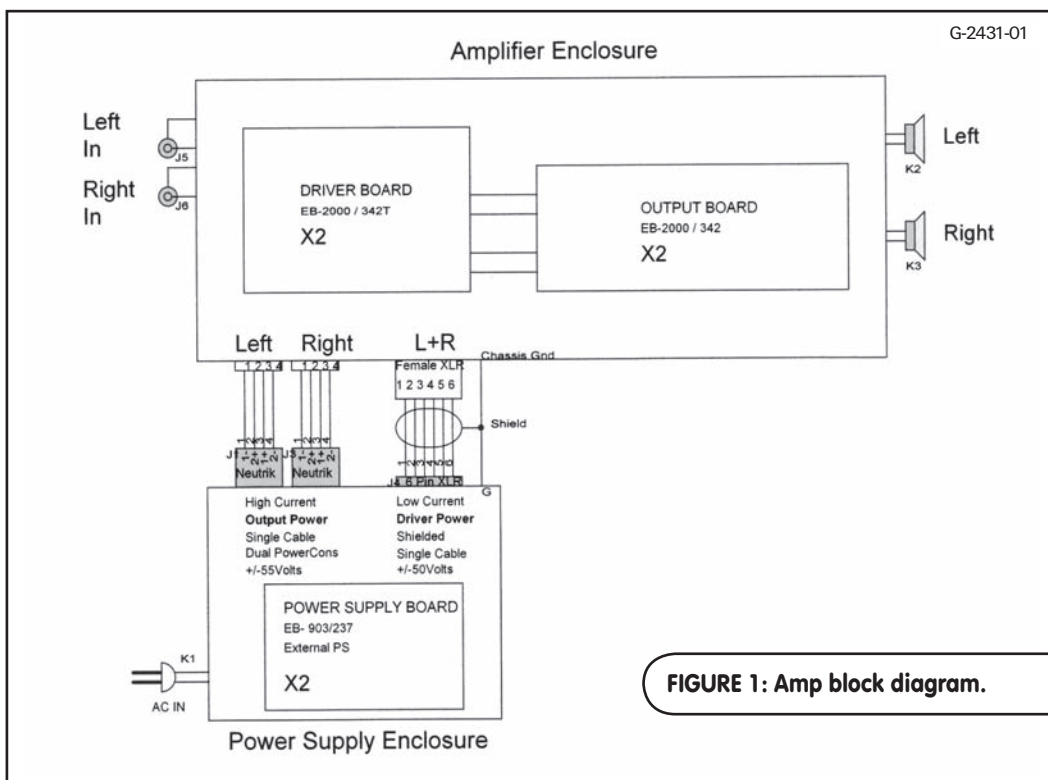


FIGURE 1: Amp block diagram.



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problems in audio gear. Removing the power supply from the amp and away from the high voltage gain of the driver stage can have beneficial results similar to using a battery supply.

The lowered noise and audible improvement in the final amplifier's sound outweigh very minor losses in channel separation. And because most of the reservoir caps are in the amp chassis, high current demands are met, and minuscule losses due to umbilicals are overcome. This works because approximately one-third of the filter caps (90,000 μ F) are in the power supply, while the rest (200,000 μ F) are in the amp (Photo 2). Combined with the 2m umbilicals' small inductance and resistance, a pseudo pi network is produced, helping to attenuate any residual ripple or noise, essentially making the cables part of the power-supply design.

Less obvious are the benefits to DIY builders. This power supply will be used on several other different amps, some MOSFET, some bipolar, all with different topologies. Up to half the cost of building any amp is its power supply. This will save time and expense when experimenting with other designs. But even more important, eliminating the power supply as a variable will give you insight into the amp's subtleties, by knowing that changes in amp design alone have caused improvements (or not) in sound and performance.

Because there are no transformers in the amp's chassis, it is much lighter and easier to move, and transformer-induced hum is eliminated. Placement of the power-supply unit is flexible so it can be put on the floor out of the way or hidden. While working with these

power-supply voltages imposes some limitations, you can use methods such as regulation and others to adjust them to required levels.

OUTPUT CONSTRUCTION

Start with the output boards, which I constructed first and mounted to the main heatsinks (Photo 3). This gave me the dimensions needed to mount the drivers on top and also gave me an idea as to the size of the enclosure. Because of the integral nature of the output modules, drilling and tapping were done first. I soldered in all passive components and left the MOSFETs unsoldered until the last step. Using the stuffing guide as a template (Photo 4), I marked and tapped all holes on the heat-sinks. This included measuring and tapping four holes for the driver board mounting plate.

You must take care in the final step when soldering in the MOSFETs. You must bend and test-fit leads onto the mounted boards before soldering.

Tighten the MOSFETs down first (with silpads!), then solder them in last to avoid putting pressure on the devices or their leads. Because all parts (semis

PHOTO 4: Stuffing guide used to mark MOSFET holes.

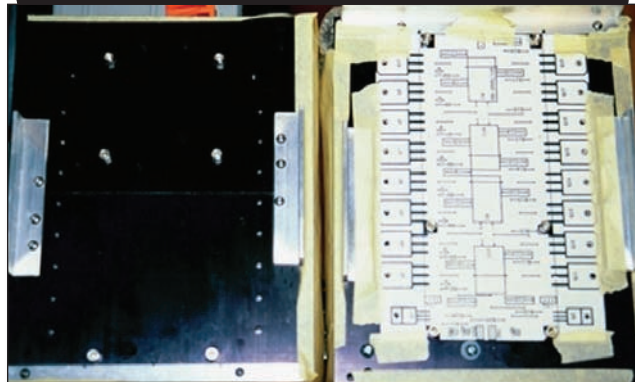


PHOTO 5: Completed driver.

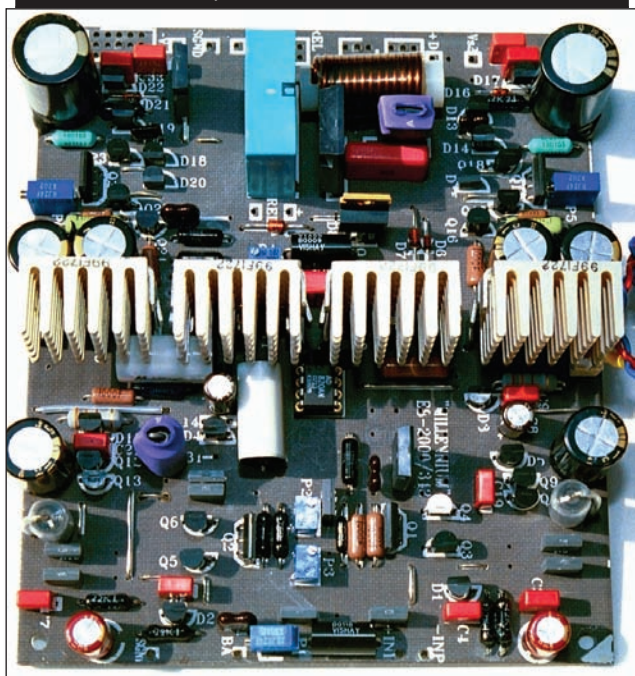


PHOTO 6: Driver and output mounted to heatsink.

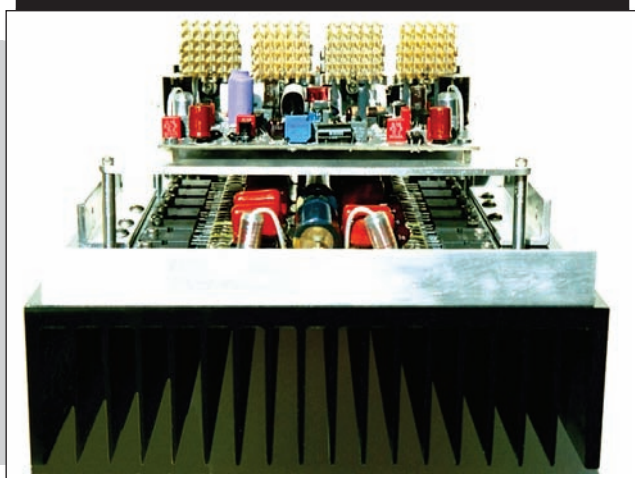
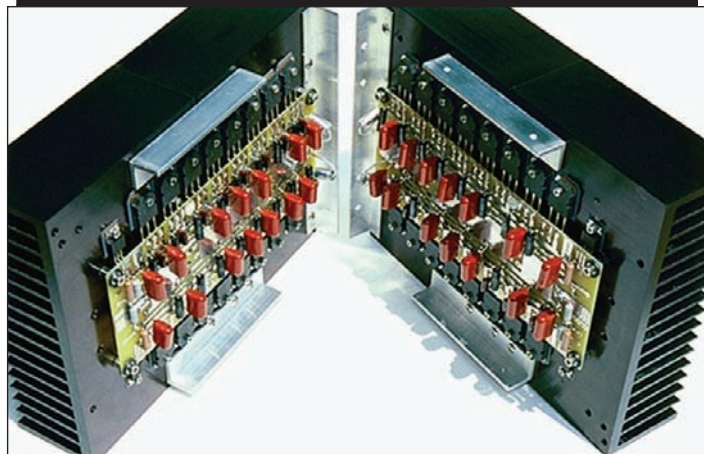


PHOTO 3: Output boards mounted to heatsinks.



in this case) are clearly labeled and placed in their own plastic bags, sorting and keeping track of what you are doing and what needs to be done is made that much easier.

DRIVER CONSTRUCTION

This PCB requires some degree of skill in soldering, and might be beyond the weekend builder. But if you have military or other soldering experience, you should have no trouble. You can purchase these PCBs as either standard fiberglass (FR-4) or Teflon (more expensive). Because of Teflon's excellent heat resistance and dielectric properties, I used it here for the driver board (**Photo 5**). The stable dielectric properties benefit this circuit because of the high gain that takes place and therefore have a more significant effect on the sound. Along with the PCB and semiconductors, I also received the relay, the inductor coil (L1), and the TO-220 heatsinks.

The rest of the components are made up of Vishay, Holco, Caddock, and Dale RN60 resistors. Cerafine, Wima, and Blackgate caps make up the bulk of the caps. The heatsinks provided are adequate, but I modified them by mounting crosscut sinks designed for a video chip (**Photo 5**). I attached these using 440 screws and thermal epoxy (Arctic silver).

There are two reasons for this: First, the boards will be mounted on their sides, reducing the cooling efficiency of the standard sinks (new ones are crosscut and work well at almost any angle). Second, I will be trying higher bias currents, with various other changes, and want to avoid heat stressing the MOSFETs (**Photo 6**).

The driver is a fairly complex PCB—some traces are thin as well as close and must be examined for solder bridges, splashes, and small metal objects, which could short these traces together. I recommend using a small handheld blue LED flashlight, which is popular and widely sold. Just make sure it uses the blue (I believe near ultraviolet wavelength) LED. After virtually inspecting with white light, I use the blue light to illuminate small particles and other debris missed by the first inspection. Blue light also illuminates cold joints

and flux residue missed by other visual methods.

MOUNTING THE DRIVER

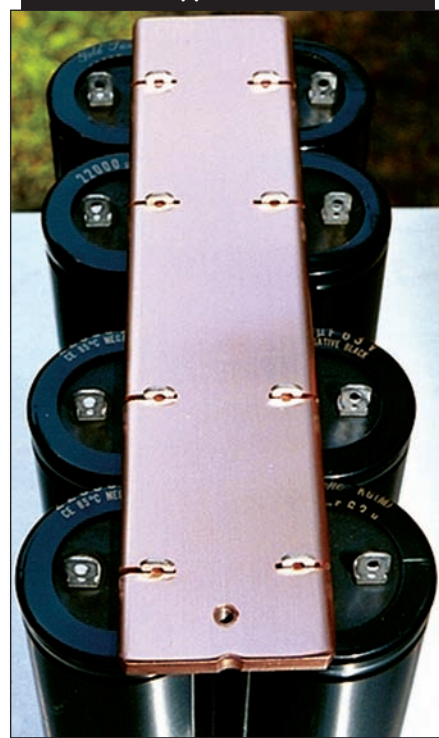
Once this was completed, I mounted the driver to the main heatsink (**Photo 6**), above the output board on a 5" × 6" aluminum plate. I installed insulating plastic (stuff used in switching power supplies) directly under the driver PCB to avoid any accidental shorting. On the bottom of the driver's aluminum plate, I installed a 1/8" thick silicon steel plate roughly the size of the driver board to increase shielding from the output board directly below it. High currents run through the output board and induce electric fields that can cause problems on the high gain driver circuitry when it's that close. You can't see the plate from the photos, but it's there.

RESERVOIR CAPS

Because even Class A circuits draw more current on peaks, most of the power caps are placed in the amp itself. Not wishing to use the three leg brackets typically used to mount caps, I devised a way to mount them that

also serves as the ground bus (**Photo 7**). I picked up these solid copper brackets (**Photo 8**) from a metal recycler and cut them to hold two banks of four caps.

PHOTO 7: Copper Gnd bus.



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I had 12 Gold Tune 22,000 μ F caps that use a solder tab, though screw terminals would be the best way to do this. I needed to use a 100W iron and let the copper bar cool down after soldering each terminal to avoid damaging the caps. The trick was getting it hot fast, flowing the joint, and helping it cool down fast with a damp sponge, before the caps became too hot.

Once this was completed, I used large chrome Allen bolts fed down through the middle of the four caps and screwed into a large standoff or hardware store coupler (**Photo 9**). You must take care to insulate these with heat-shrink and Teflon or nylon washers so that contact is not made with the GND bus bar (**Photo 8**). I used high-temp silicone on top of the caps just underneath the bus bar (sparingly), running down the four corners of the caps to strengthen everything, but not so much as to make it hard to replace one of the caps if needed. I placed some very thin high-density foam ($\frac{1}{16}$ ") on the bottom of the four-cap bundle to keep pressure even on all four.

Finally, there is no need to over-tighten the Allen bolt. I used Loctite to keep the hot/cold cycling from working it loose. This method has worked extremely well, takes up very little space compared to other brackets, and is rock solid. Almost $\frac{1}{4}$ " thick, the copper I used was overkill, but it conducts very well, so you could use thinner copper or even aluminum.

I used insulating plastic to keep accidental shorts away from the ± 50 V terminals and the copper GND bus (**Photo 10**). I installed four 2 μ F metalized polypropylene caps across each 50V supply on the output board (**Photo 10**, top left, right). These are shunted by four Seimens 10nF polystyrene caps to improve the power-supply response to high-frequency demands.

REAR PANEL CONNECTIONS

I used a GND star, which simply involves two 1" $\times$ 1 $\frac{1}{2}$ " copper tabs mounted on the

back panel on Teflon spacers to isolate them (**Photo 11**). All GNDs (star Gnd) are tied to these tabs—one tab per channel. Power for driver and output sections enters the panel in the center (**Photo 12**). These consist of Neutrik four-pin Powercons (2), one per channel for output power (**Fig. 1**). They use heavy silver-plated contacts rated at 20A per contact, and are keyed as well as locking. Each cable carries ± 50 V, PSGND, and AMP-GND.

This scheme works well, and has no GND loop problems or hum (in fact, it's absolutely quiet). I slipped large ferrite cores over each channel's bundle of power cables where they enter the amplifier. These help attenuate high-frequency EMI and other RF noise.

Driver power is actually two separate cables (L+R) in one sleeve, connected to one Neutrik 6-pin XLR. Each three-wire cable within (± 55 V, Gnd) has its own braided copper shield, which is grounded to the chassis only—on both ends. They are also connected every foot with a piece of the braid

wrapped around both shields and soldered. This dual shield connects the two chassis (GND), keeps left and right channel power separated, and shields them from external noise. Remember that this is power for the high-gain driver boards, so it is important to keep the

PHOTO 9: Ready to mount right channel cap bank.

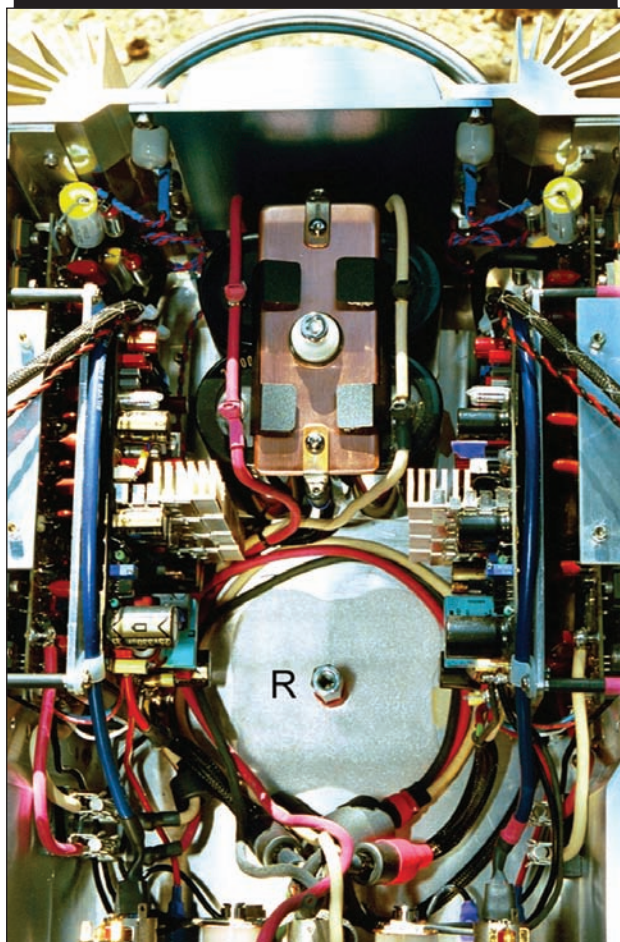


PHOTO 10: Left channel caps mounted with Gnd bracket.

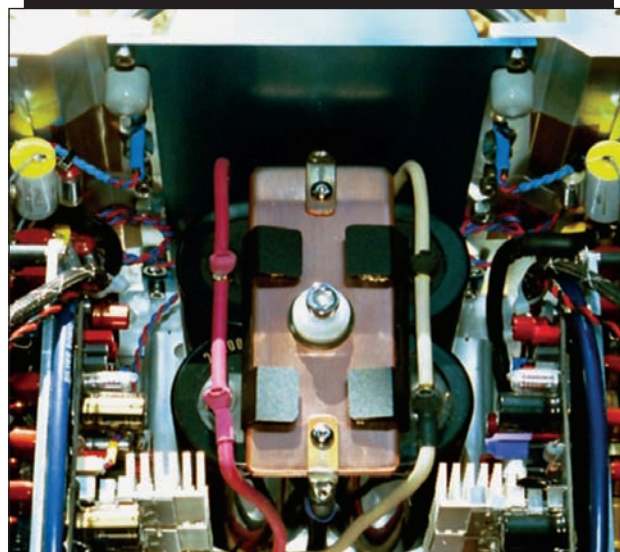


PHOTO 8: Gnd bus brackets and mounting hardware.



power coming in noise free.

Final connections include left and right RCA inputs, XLR balanced with a locking switch for balanced or unbalanced selection. The WBT heavy-duty speaker connectors are on the bottom. Splitting up the left and right inputs (usually side by side) works well here because there are essentially no stray magnetic fields from a transformer. In some cases transformers cause hum when inputs are divided in this way,

but here it serves to improve channel separation.

Unbalanced connection from RCA to the driver input is made with solid silver Teflon insulated wire, which is twisted (pair) and pulled through copper braid. The braid is chassis-grounded on one end, floating on the other. Balanced operation uses Silver Sonic BL-1 Series II silver-plated cable.

The amp is positively quiet, with no hint of hum or hiss. Even with the

volume way up, I can barely hear any hiss at all when it is driven by my McIntosh line-amp. This speaks volumes about the excellent Borbely design, and I believe the external power supply certainly has helped in this regard, but I must compare this amp with the monoblock version before I can make an unbiased judgment.

POWER SUPPLY UNIT

Power Supply Construction—Building

PHOTO 11: Front/top view of completed amp.

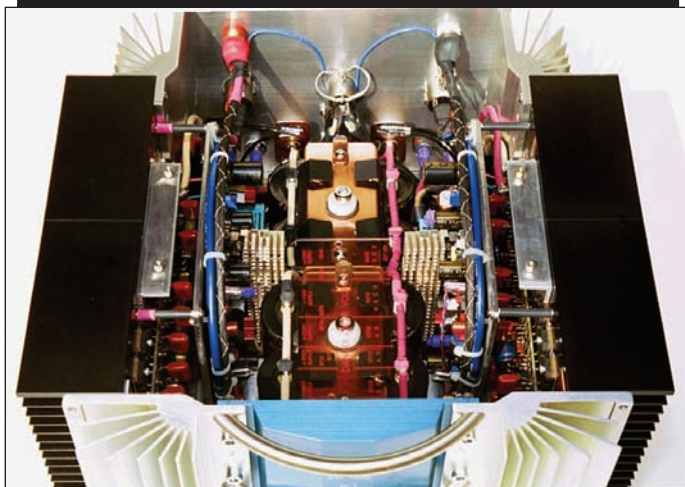
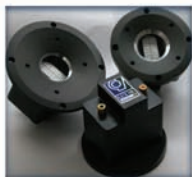
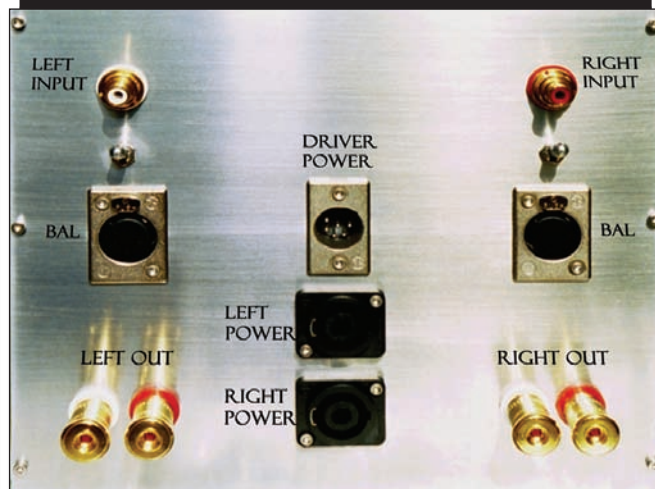


PHOTO 12: Amplifier rear panel.



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DEQX PDC 2.



the external power supply (**Photo 13**) for this amp required an extra heavy chassis to support the heavy transformers and other components. I turned to an old Hewlett-Packard tube pulse generator that had been parted out years earlier because of an open high voltage transformer and burned PCB. I chopped down the width, added some paint (auto), hardware (**Photo 14**), and aluminum to cover it.

Mounting the transformers involved a bit of luck, as they just fit onto the sides, but I needed to pot them with hi-temp epoxy and thread some $\frac{3}{4}$ " nylon rod for mounting bolts. Plitron does this all the time, and if you use the correct potting epoxy (McMaster-Carr has it), it will work (**Photo 19**). You must make sure that the mounting bolts don't touch when mounting the smaller driver transformer (**Photo 15**), which could cause a single loop, overheating, and the transformer to fail. Grain oriented silicon steel (GOSS) shields mounted around the periphery of the output transformers provide attenuation of any stray fields. 10Ga copper wire is used for all output power connections, and 16Ga for driver power.

Photo 15 shows details of each PCB mounted at each end of the enclosure, separating left and right power as much as possible. I made brackets to fit behind the PCB supporting the top and bottom of the boards.

Power caps are supported with aluminum brackets on the bottom and copper brackets on top, which also serves as the GND bus. I used separate transformers, so I needed a shielded 12V transformer to power timers and relays (bottom left of **Photo 14**). This means all 625VA goes to the output board and there is no crosstalk between windings as with transformers containing windings for both driver and output power.

For power rectifiers I used IXYS DSEP 30-12 soft recovery (called Hyperfreds) diodes for the output section.

These work well and exhibit minimal noise. The power-on switch is a NOS Cutler-Hammer heavy-duty 20A DPST.

REAR PANEL CONNECTIONS AND CABLES

The power-supply rear panel (**Photo 16**) brings out all the power for the output and driver boards. As with the amp, I used Neutrik Powercons for the high current output power. **Photo 16** shows how these are mounted sideways, allowing you to grasp the locking mechanism to remove them. Two four-pin cons are used, but Neutrik makes an eight-pin version with the same ratings that you could also use.

I like these connectors so much, in fact, that I used the three-pin AC Powercon for the AC mains coming into the power supply. Originally using an expensive IEC AC connector (**Photo 17**),

it kept working loose and pulling out with heavy 10Ga cable, so I switched to the Neutrik (**Photo 17**, white on blue). With 20A silver-plated contacts and heat-resistant plastic, you can screw on or solder wires. These are tough, well-made connectors. Mouser carries all of the Neutrik connectors (see resources). I used double-insulated 10Ga, 600V copper wire for the output umbilical (**Photo 18**).

Driver power uses the Neutrik six-pin XLR (female on power side, **Fig. 1**), with silver-plated 8A contacts. The

PHOTO 13: Front view of completed power supply.

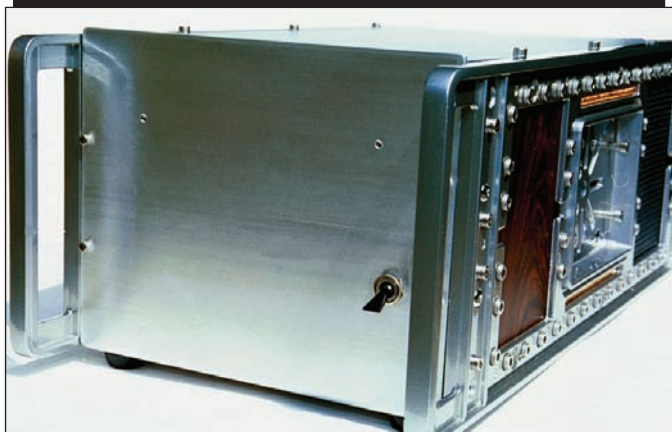


PHOTO 14: Recycled HP chassis after paint and hardware.

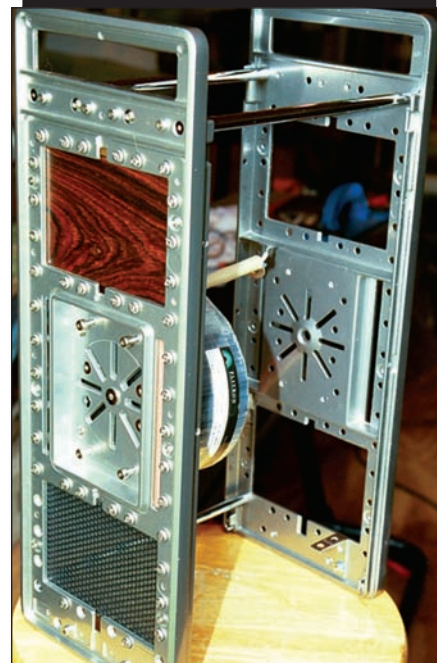


PHOTO 15: Top view of power supply.



twin copper braid used to shield each channel's power wires ($\pm 55V$, GND) also ties the two chassis together. This keeps any external noise sources from contaminating driver power, and the twin shields keep interchannel crosstalk down.

I was concerned that ground loops might be produced using this method—it was so simple, but it performed better than I ever expected. I used several GND straps to ensure good connections between the sides, front, and back panels of the power-supply enclosure. The last strap goes to the safety GND on the AC Powercon coming in. After painting the power-supply chassis, I wanted to make sure all these panels were connected electrically. This was not a concern with the amp enclosure, because I used no paint.

FINAL TOUCHES

To complete the power supply, I attached two pieces of cocabola wood with brass brackets in the front and inserted perforated aluminum in the back to allow airflow (**Photo 14**). All of the (handy) mounting holes not used were filled with 10-24 Allen screws and Loctite to avoid vibrating out. Using the old HP test equipment for this beats dumping it in a landfill—even if it was beyond repair, it had a ton of useful parts. The big heavy handles make moving the power supply so much easier, and the innumerable mounting holes make it perfect for building just about anything, but please don't tear one of these apart if it can be repaired. Old tube test equipment like this is classic, and should be restored if possible.

Because I made the amplifier enclosure using surplus heat-sinks and custom-made parts, you can't go out and buy them. But with some imagination, anyone can build something that looks unique or one-of-a-kind for next-to-nothing. It just takes more time rather than money.

You can have some of these parts made.

The top (lid), and the front panel (blue) were machined to my drawings by Maxxus in Richardson, Tex., and blue anodized for a reasonable amount. The handles are heavy stainless steel, and made for cabinetry. The entire project was done for less money than a mid-

priced, mass-produced amplifier.

LISTENING

The sound of this amp is very good. Imaging is wide and very stable, with detail in the mids and highs, bringing out subtleties missed by lesser amps. Borbely's designs are sophisticated and rival just about anything out there.

Mr. Borbely provided helpful advice and I know of no one else who sells kits in such a variety of ways. Larry at audiokits.com also carries most of the Borbely kits, so the support is there if you have trouble. Thanks to Erno and Ed for their patience and help getting this project done. *ax*

Rick MacDonald, after 15 years as an engineering tech designing and prototyping broadband RF antennae and GPS satellite subsystems, moved into software engineering with E-Systems/Raytheon. Rick's most recent work has been with digital audio, composing music with MIDI and editing audio for games, software, kiosks, and websites for Gateway, Tandy, and Voyetra, among others. Rick has also written articles for *Recording* magazine, and has published several books on interactive audio and computer music. He continues to pursue the perfect power supply for all his audio projects.

PHOTO 16: Rear view of power supply.

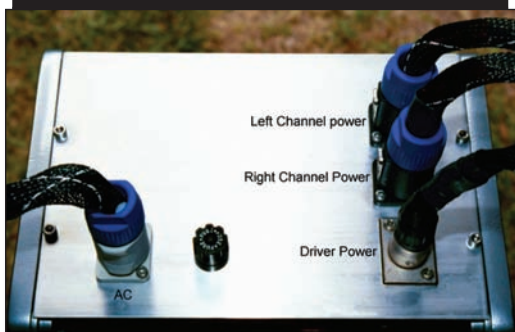


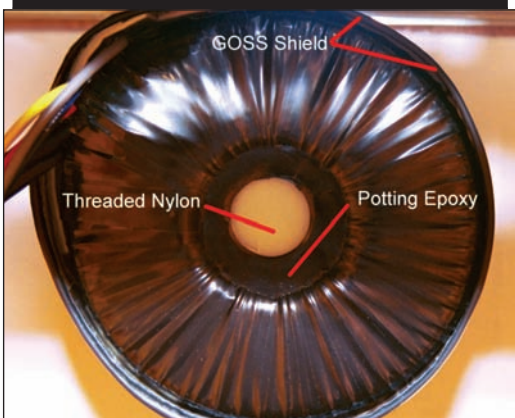
PHOTO 17: Power cables.



PHOTO 18: Amplifier power umbilical.



PHOTO 19: Plitron transformer after potting.



RESOURCES

Borbelyaudio.com—Amp PCBs, kits, parts, cases, Cerafine caps, tantalum resistors, silver mica caps, FETs, transformers.

Audiokits.com—Amp PCBs, Borbely kits, audio parts, enclosures for Hpamp, FETs, MOSFETs.

Percyaudio.com—Components, braided shield, Caddock, Kiwame resistors, MUSE caps, Goldtune caps, silver wire, audio parts.

Mouser.com—Components, Neutrik Powercone, XLR connectors, RCA jacks, more.

bgmicro.com—Surplus heatsinks, batteries, surplus parts, much more.

DIYHIFISupply.com—DACT attenuators, audio components, Kiwame resistors, kits.

McMaster.com—High temp epoxy, adhesives, nylon rods, copper, aluminum.

Digikey.com—IXYS Hyperfreds, components.