

The Borbely Annals

Erno Borbely is not a man given to bragging about his accomplishments. But from the venerable Hafler DH200 to today's high-performance all-FET amplifiers from Borbely Audio, he has left his mark on 40 years of technological audio advancement. Jan Didden looked him up in his home close to Munich, Germany, and talked with him about audio and other tidbits.

By Jan Didden



PHOTO 1: Mr. Borbely shows the book on semiconductor technology he co-authored while working in Norway.

Jan Didden: Erno, when we had our first contacts to prepare for this talk, you told me of the events during the early part of your life. Would you give us some background about that?

Erno Borbely: Well, I was born in that very unstable time, just before WWII, in the Hungarian village of Aszofö. Because I found some electronic parts during the war, I became interested in electronics and decided I would become an engineer. After two years at the Technical University of Budapest, I had to flee my homeland in 1956 when the Russian military invaded my country. Initially, I managed to get to Austria. I spent a month in a camp until the Norwegian Student Organization offered me passage to Norway and admission to their Technical University in Trondheim. Both

the Austrians and the Norwegians were very friendly and helpful with the refugees.

I arrived in Norway on Jan. 15, 1957, and after a short stay in a camp, we students were placed with Norwegian families and studied Norwegian at the University of Oslo from January to June. I was admitted to the Institute of Technology, University of Trondheim, and continued my studies there. I earned my master's degree in electronics in 1960; my thesis was the design of an arithmetic unit for a CPU, with discrete Philips germanium transistors clocked at a phenomenal 250kHz! I worked at the electronics lab of the Institute until 1961, designing instrumentation for the lab. Then in 1961, I got a job at the Norwegian Broadcasting Corp. in Oslo as a design engineer. For the next eight years I designed studio equipment, both in tube and semiconductor technology. I was also teaching sound engineering courses at the Broadcasting Corp. and at the Norwegian Engineering Society. I have written textbooks and co-authored a book on semiconductor technology in Norwegian (*Photo 1*). I became a Norwegian citizen in 1964 and married Irene in 1966.

JD: How did you get to work for Dynaco in the US?

EB: Well, I met David Hafler in Stockholm and he offered me a job at Dynaco in Philadelphia, and we moved there in 1969. Working with Dave was very interesting; I had to learn to design simple, inexpensive circuits which nevertheless sounded good! I designed the DYNATUNE circuit for the Dynaco FM-5 FM tuner, for which I received a US patent.

Another interesting development was the Dynaco QD1 Quadaptor (*Photo 2*). This was a passive quadrasonic unit that you put between the stereo outputs of your power amp, and then connected two additional speakers to the QD1, in addition to the regular speakers. The QD1 extracted some of the ambience sound hidden in the

sum- and difference signals and sent that to the extra speakers. Dave had special records produced to demo the effect (*Photo 3*). This again showed that Dave was very talented and creative! Both the QD-1 and the later QD-1 Series II are still available today—for example, on eBay.

At around that time Dave and I also started to discuss designing a big power amp, and he asked me to look into the possibility of a high power output stage.

Unfortunately, Dave then decided to sell Dynaco to TYCO, and he stepped down from daily management. They brought in Frank Johnson as president and he named me Director of Engineering in 1972. So, I was working on that high-power cascode output stage and Frank brought in Jim Bongiorno to tackle the voltage amplifier stage. But progress wasn't fast enough for



PHOTO 2: Dynaco surround sound QD-1 Quadaptor.



PHOTO 3: Dynaco had special records pressed to demonstrate the surround-sound produced with its QD-1.

Frank, and it was decided that I and another colleague, Harry Klaus, would team up together to complete the 400. Anyway, I was wrapping up my work on the 400 at the end of 1972 when I decided to leave Dynaco. I suggested doing a patent investigation into the cascode output stage, but I guess Dynaco never did. Overall, I think the 400 was overkill. Harry Klaus designed a simplified version later on, the 410 (simpler heatsink, no Dynaguard, and so on), which was also a better sounding amp.

JD: That was when you moved back to old Europe?

EB: Yes. We moved to Switzerland and I worked as Applications Engineer/Application Manager at Motorola Semiconductor. I met John Curl there and we had a good time discussing audio circuitry, and from my position as application manager I was able to provide John with samples of low-noise Motorola semiconductors. I was designing low-noise circuits with bipolar transistors and JFETs, power amplifiers with bipolars, and also an FM tuner with dual-gate MOSFETs. You see, initially, JFETs became available as an alternative to low gain and low Zin bipolars. They were used in very diverse equipment, instrumentation, RF, later also audio. At first they couldn't match the low noise of some of the better bipolars though, but that gap was closed quickly. The early ones had appreciable Cdg, so we cascoded them, first with bipolars, later with other JFETs.

I was pretty happy in my job when Dave Hafler came to visit us again in Geneva in 1977 and told me that he was going to start a new company, and offered me a job as Director of Engineering. So, we moved back to the States in 1978 and I worked for Dave again at the David Hafler Company. I designed the DH101 preamp and also the DH200 (Fig. 1) power amp, which was the first one to use MOSFETs in the US.

JD: These were the Hitachi lateral MOSFETs?

EB: Yes, for me these sound the best of all MOSFET types. At low bias they

sound kind of soft, and come very close to tubes. They have relatively low Gm but the negative tempco is a plus. Vertical types such as the Toshiba have higher Gm but a positive tempco, which makes it more difficult to stabilize the quiescent conditions. They can sound quite good as well, especially in the bass department, although for full-range I would always prefer the Hitachis. And the Hitachis can sound good with only 100mA, while the Toshibas would need at least double that.

I don't like the IR-type power MOSFETs, although they have a very high Gm. When I used them I had an extra identical device on the heatsink as the bias regulator to keep the positive tempco under control. They measure well but they are not my favorite for sound quality, unless you go to very high bias currents or other topologies such as Nelson Pass is using.

JD: You mentioned tubes; have you done any tube work in audio?

EB: Oh, yes, I started out in tubes in Norway. It's a funny thing with tube power amps. In my opinion—and, of course, this is a very general statement—they have less resolution and transparency than a good FET amplifier. Tube amps generally do color the reproduction, and that can actually be quite pleasant, but it isn't the original sound. Yet, I very much enjoy listening to my favorite music through a

tube amp. I loved those E130s! One of those audio mysteries that we'll probably never solve!

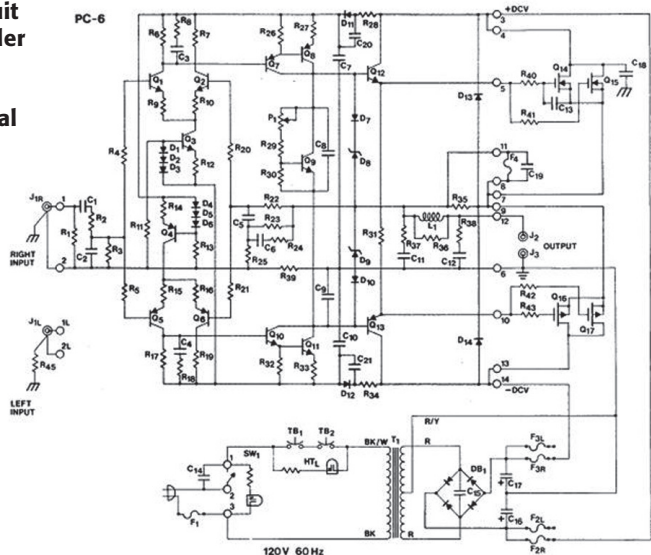
JD: Would you use negative feedback in those tube amps?

EB: Well, for power amps in general, I am convinced that negative feedback (nfb) is a worthwhile tool for the audio designer. I don't believe that nfb "kills" the sound or that it comes too late to do any useful correction because it can only correct after the fact. Delays in audio equipment are too short for that; I mean we have phase shift in the forward path, but the effect of that is to limit the positive effects of nfb as frequency goes up. On the other hand, nfb should not be the only tool used. But with tube power amps in particular, I think you should use some feedback to bring down the output impedance. An open loop tube power amp without nfb has appreciable output resistance and it will be very difficult to keep the speaker under control.

JD: You're not afraid of TIM and related overdrive issues in high feedback amplifiers?

EB: Otala showed us the importance of adequate slew rate to avoid internal overdrive and a few other things. TIM in itself was not new but it did re-focus us on some important issues and as such contributed to better design practices, but it was only one of

FIGURE 1: The circuit diagram of the Hafler DH200; you can download the full construction manual from www.hafler.com/techsupport/pdf/DH-200_amp_man.pdf.



the important issues. I think Matti at a later stage realized that also. Walt Jung's series on slew rate distortion was another important contribution. My preference is to have a reasonably linear forward path in an amp, and then to add some feedback to it for two main reasons: first, to stabilize the DC and AC conditions, and, second, to have a reasonable damping factor to keep the speaker under control. This is an important point. You shouldn't use nfb to "fix" a bad design, but to clean up and stabilize the operating parameters of an already pretty good circuit. I can get good sound with or without feedback, but with some feedback it becomes better—repeatable and stable. I am always measuring my designs for open loop linearity. I have a bank of capacitors that I use to break the feedback loop for AC, but leave the DC loop intact to avoid excessive offset and drift. Every time I work from these principles, I get good-sounding amplifiers, and my customers seem to agree!

JD: So, you were back in the States working for Dave.

EB: Not for very long, alas. We did buy a house in New Jersey, and Irene spent a year fixing it up. Unfortunately, I had some disagreement with Dave about shares in the company, and decided to leave after just over a year. This was a big mistake, as the David Hafler Co. did very well for another ten years and made a lot of money on the sale! And, of course, Irene never forgave me for leaving the nice house she built up. We moved to Germany and I worked at National Semiconductor as European Training Manager. I started publishing my articles in *The Audio Amateur* and the Danish *High Fidelity* journal in the beginning of the 80s. We started Borbely Audio with Irene in 1984, initially to supply difficult-to-find components for my designs in (then) *The Audio Amateur*. Later on we started to sell some of the kits that I published. Irene was running the show, as I was busy at National, and could only contribute during the weekends.

JD: If memory serves me well, all your *Audio Amateur* (currently *audioXpress*)

designs were strictly FET-based, including the power supplies.

EB: Not really. The first power amp I published in *Audio Amateur* 2/82 was all bipolar, except, of course, the MOS-FET output. The first JFET input phonos and line amps were also using bipolars in some stages—see, for example, "The Borbely Preamp" in *AA* 4/85. But, I like FET devices; I can design circuits with them that are not very complicated, that are well reproducible without tricky adjustments and compensations, and, most important of all, they really sound good. Also, their wide bandwidth is a big plus. There is a difference between sounding very good and absolute measured linearity; I don't have to convince you of that. As I said earlier, tube amps don't generally measure well but can sound good. But for me, FET-based amplifiers overall sound best in most situations, speakers, and music.

JD: Ironically, we now see that many of the JFETs are becoming obsolete, such as the Toshiba J74, following the fate of the obsolete dual K389 and J109.

EB: That is right. I think it was John Curl who pioneered the E110, E212, and E175 in the JC-2, and started using the Toshibas in the Dennessen JC-80. I am still using them in my own designs. There are companies that market replacement devices, but in my experience they are not as good as the original Toshiba ones. In fact, there have never been good replacements for those big chip Toshibas with 35Ω noise resistance, which were already obsolete in the 90s.

JD: How about power supplies? Many of your designs use regulated supplies, with FETs, of course!

EB: Yes, call me Mr. FET (smiling). There are two types of supplies I use. One is an LC input supply followed by a very low noise, very stable series regulator, with discrete FETs. The other is a very low noise shunt regulator. It's often a matter of personal preference. My friend Are Waagbø used a combination of a series current-source feeding into a parallel shunt, and that is probably the very

best you can do for regulated supplies. He described the design in his February 2008 *audioXpress* article ("Shunt or Not," p. 30).

What I find quite important in supplies is to use reservoir caps with the lowest ESR practicable, and use lots of it. I believe in very stiff raw supplies. That makes sure that the raw voltage going into the regulator is as smooth as possible. And, by the way, Walt and you have also done a lot of good work on regulators!

My preference for power transformers are R-cores. They have the best isolation from the mains noise and interference, and are dead silent mechanically. If you use toroids, you should use potted types to make sure there is no mechanical noise.

JD: I agree. Toroids are too wide-band to use for low-level circuitry. I used to have transformers wound for me in Germany. For, say, an 800VA transformer I would tell them to wind it on a 1200VA core. Those transformers would be absolutely silent, mechanically, without potting. Of course, you pay the 1200VA price. Another question: I don't remember seeing any protection system on your power amps?

EB: Oh, I have an output protection circuit for those customers who wish to use one. I never used one with my own amplifiers. Those output FETs are so rugged, I never had any problems with that. I noted on your website that you favor that special-purpose output relay from Amplimo, and one of my friends told me I should look into it; I may do that.

JD: When did you decide to retire from National?

EB: That was in '97 when National closed their European Training Center. I continued and expanded designing and selling high-performance kits worldwide. We have experienced some problems lately with the €/ \$ exchange rate (1:1.55 at the moment) and for our most important market, the US, pricing is difficult. We also face significant problems with the Postal service. Besides the fact that Germany has closed most of the normal post offices in our neighborhood, there is

no basic insurance on packages to the US, Canada, Australia; starting July 1, 2008, the German Post service will no longer accept any insured packages to the US, which forces us to use more expensive options.

Besides the kits, I have been designing amps for OEM customers. My most important OEM customer was PBN Audio in California. Peter Noerbaek of PBN is a very famous speaker designer and also built some of the best amps on the market. I was hoping that Aural Audio, which was established by Larry Black, would become the next high-end supplier, and indeed Larry got some very good reviews for his first products. (www.6moons.com/audioreviews/aural/audition.html) Unfortunately, he passed away at a very early age of 47. One of his dealers is considering resurrecting Aural Audio; we'll see what comes out of it.

JD: I noticed that most of your designs are fully published with schematic diagrams and even board layout, either at your website or in *audioXpress* articles. You make a point of noting that those designs are your intellectual property and that commercial users should get a license. Are your designs being copied without your approval?

EB: Unfortunately, yes, there are unscrupulous individuals and companies that try to make money from my work. Not just the single-person Far East outfits, but also established European and US-based companies. I'm sure my fellow designers also suffer from it. It is plain and simple theft, and difficult to prevent. I provide support and assistance to my clients when necessary, which those copycats don't, of course, and that is also worth something. (Says Mrs. Borbely, half jokingly: Erno is too nice. He can easily spend an hour on the phone to explain to a customer the ins and outs of one of his kits. He likes that kind of interaction, to be a teacher.)

JD: You've seen audio develop to a very high standard the last 40 years. Where will it go the next decades?

EB: I'm not sure. On the one hand, I fear that the "iPod generation" no longer cares about high-quality au-

dio, but more about having their favorite sound always and everywhere. Supported by producers who seem to be mainly concerned with getting the highest loudness levels. The situation is neatly described in an article in *Rolling Stone* magazine (www.rollingstone.com/news/story/17777619/the_death_of_high_fidelity). On the other hand, I see still a lot of young people going into audio DIY for serious listening, besides using the iPod or MP3 player when they're on the road. But it must work both ways. It's up to the record producers to make sure we have well-produced and recorded music that makes our equipment worthwhile!

In a sense, the possibilities for DIY audio are greater now than 40 years ago. You don't need to do an extensive study but you can still get the DIY-audio reward from building relatively simple tube amps or gain clones. So, maybe the future of quality sound reproduction is not that bleak after all. And an added advantage of tubes, for DIY, is that they're not converting to SMD-tubes in the foreseeable future!

JD: Do you participate in any of those online audio forums?

EB: Not really. I sometimes scan the discussion at diyaudio.com, for example. But the tone of some of the comments is often very hostile and negative. I understand that people can have very strong opinions on audio issues, but it should at least be possible to discuss in a civilized way, without using swear words or insults. I think that's why Walt Jung left that board, and look at some of the attacks John Curl has to endure. I think the main problem is to separate the chaff from the corn; there are some very good discussions there.

JD: I have been participating at [diyaudio](http://diyaudio.com) for about five years now and I know what you mean. I have also written some posts that in hindsight I regret. Part of the difficulty is the mix of, on the one hand, accomplished designers such as John, Nelson Pass, Charles Hansen, and so on, and, on the other hand, young, inexperienced DIYers. There are those who recognize the great possibility to learn, and others who want to show up the old guys.

It's a very direct and immediate medium and that appears to increase the emotional content. The discussions in the *AES Journal* and, in earlier times, in *Wireless World* were also often very tough and potentially damaging, but in a printed medium it seems less direct, and, of course, you can't react immediately so you mull it over and that softens the reaction.

EB: Yes. It is a worthwhile and very efficient way to exchange information and opinions, but it should be properly moderated. I think it would be a good move by *audioXpress* to sponsor an audio forum related to its articles and publications.

JD: Do you use simulation in your design work?

EB: Not as much as I've done in the past. I remember getting some ADI SPICE models from Walt Jung in earlier times. Seems to me, unless you are sure of very accurate models, you can have a design that seems fine and sounds bad or vice versa. I don't say a simulator is not valuable for some work; it is a great tool for "proof-of-concept" type of problems. I have less need for it nowadays.

I have most of the test equipment I need in my lab (very well equipped lab!—**JD**). I have a vintage HP distortion analyzer, but I use Bob Cordell's audio generator from his 1981 *Audio* article (www.cordellaudio.com/instrumentation/thd_analyzer.pdf) because it is better than the HP built-in oscillator. I can measure noise to 100µV full scale. I'm also thinking of getting some of Bill Waslo's stuff from Liberty Instruments, for the Juli@ soundcard. They're very flexible and high quality.

[At that point Mrs. Borbely (call me Irene) enters the lab. It is immediately clear that she knows the audio scene very well. They run Borbely Audio together, with Irene handling all the business issues, paperwork, money, shipping, and so on. As Erno mentioned before, it wouldn't have worked without the strong support of his wife. And her Hungarian goulash is the best I ever tasted, not to mention her beautiful paintings that grace the walls of the Borbely

residence.]

JD: What's the latest project you have added to your lineup?

EB: That would be the DAC (www.borbelyaudio.com/pics/HB_DAC1704_V1_01b.pdf). Together with Miklós Kiss of Whiteful Audio (www.whiteful.ini.hu) and Johannes Frederiks we've done a lot of research on that—jitter, oversampling, filtering. We get very low jitter by using a

Sample Rate Converter, and then re-synchronizing the signal again after the SRC. We don't use oversampling filters because their pre- and post ringing causes the sound to be a bit "slushy" by want of a better word. We do the upsampling by a very precise interpolation in the SRC, and no down sampling filtering is needed when using the direct downsampling feature of the new high-end chip (SRC4392) from Texas Instruments.

[To verify the difference between an SRC as "oversampling filter" and a direct audio chain without any digital filtering, the design includes a switchable non-oversampling mode—**JD**] Miklós designed several test boards, and finally we selected the best R/2R DAC currently available, the PCM1704 in a fully balanced configuration (using two 1704s per channel). Johannes designed the final HB-DAC1704 board. I'd been trying many different DAC chips before deciding on the 1704, which for me gave the best overall sound. And the best I/V solution then is an active I/V; preferably with many-MHz bandwidth.

But I have also done a lot of research into power amplifiers since I developed that Hafler DH200, which has culminated in my Millennium and Ribbon power amps. They are similar in design, with the Millennium able to provide somewhat more output power (**Fig. 2**). With a maximum supply voltage of $\pm 50V$ ($\pm 55V$ unregulated) and a EB-117/400 output stage (**Fig. 3**), the Millennium can deliver up to 100W into 8 Ω . If the power supply and the output stage/heatsink are chosen correctly, 75-80W of this can be delivered in pure Class-A. They both are fully complementary designs, using only FETs as active elements. The input stage is a complementary differential cascode FET circuit, using dual monolithic JFETs as input devices and MOSFETs as cascodes. The second stage consists of two JFETs in parallel and a MOSFET connected in cascode. The JFETs are operated at 8mA each, providing a total of 16mA drive for the output stage.

The bias circuit is a V_{gs} multiplier, using a MOSFET. The MOSFET itself, a T0-220 device, is selected according to the MOSFETs used in the output stage and is mounted on the output heatsink, if necessary. This ensures proper bias tracking with the different output MOSFETs. The output offset is tracked and controlled by Q7, which is a JFET-input op amp. Two shunt regulators provide $\pm 10V$ supply voltage for the op amp, while the driver itself is also fed from fully

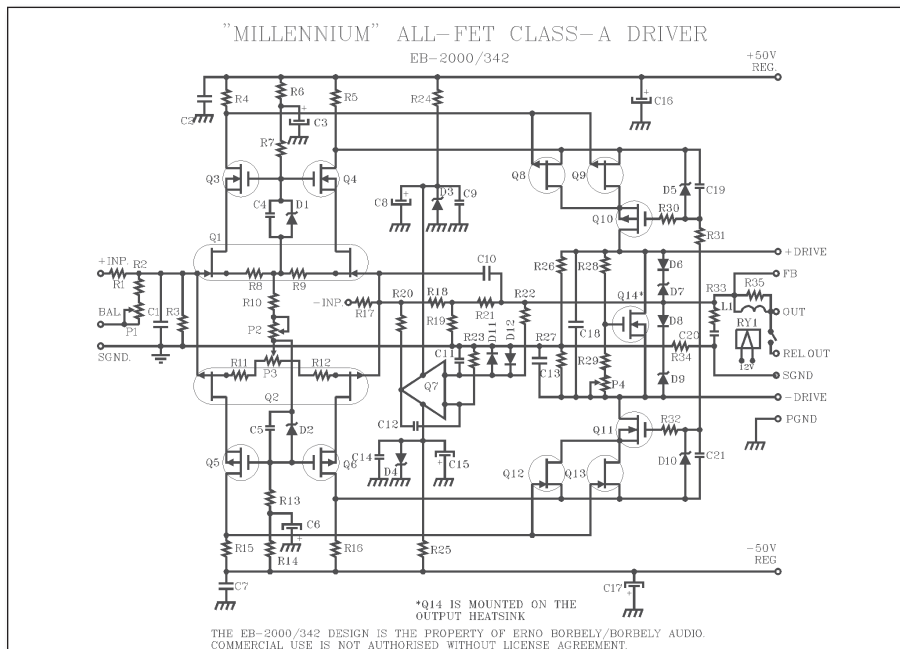


FIGURE 2: The Millennium power amp driver stage is an all-FET design in the best Borbely Audio tradition.

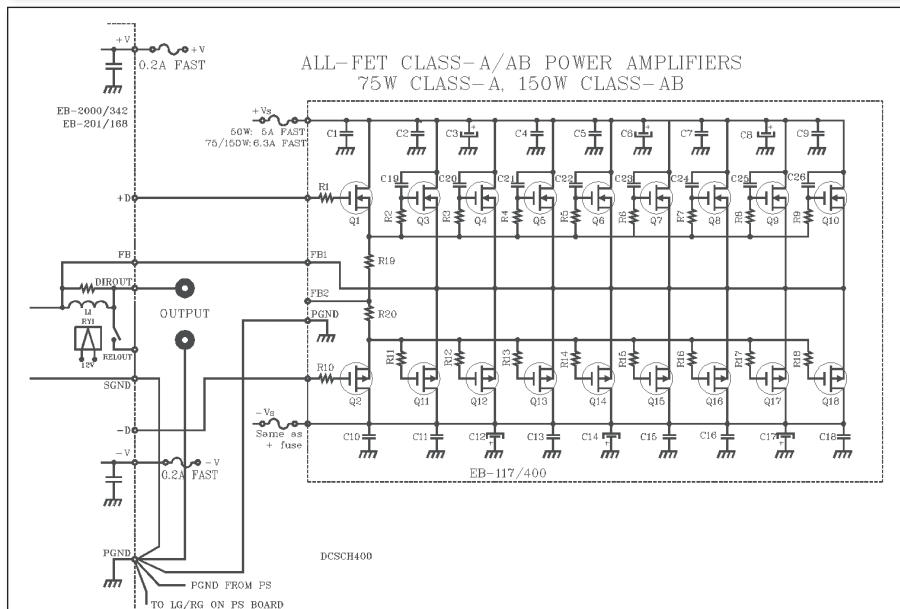


FIGURE 3: With the Millennium driver stage, this massive, matched, parallel MOSFET output stage delivers up to 75W of class-A power.

regulated, all-FET power supplies.

These power amps are all-round top performers, and really shine with ribbon or electrostatic speakers that benefit from their transparency and high resolution. And again, my customers seem to agree!

JD: I see some pretty exotic parts here.

EB: Not for exotic's sake, but I do find that parts are important for good sound. I use Dale resistors, with Caddock's as an upgrade option. When I need small capacitors, I have used silver-mica, but after a lot of feedback from my customers as well as my own evaluations, I am now favoring polystyrenes. The problem is that not many manufacturers produce them, and if they do, only a few different values. So it's a continuing search for good parts these days.

Another related concern I have is the current switch to lead-free solder and lead-free plating on PCBs. We need higher temperatures to solder them, which is harder on the parts. I realize the environmental issues, but we don't know how good, or bad, those solder junctions will be 5, 10, or 20 years from now.

JD: Do you have any distributors or partners?

EB: Yes, I have two partners at the moment: Les Bordelon of LBAudio in California and Tai-Shen Lee in Taiwan. Les is doing custom assembly for North American customers. Les' amps can compete with any commercial product on the market, both in sound quality and in professional packaging (*Photo 4*). Tai-Shen is making phono preamps for Taiwan, which is one of the biggest vinyl markets in the world.

JD: Well, Erno, we sure covered a lot of ground in this talk, and I am very grateful for your willingness to share your history, your experiences, and your opinions about audio issues. Any last things you wish to mention?

EB: I must tell you that after 40+ years, I still very much enjoy trying to push audio performance. As you

realize, I am now into my seventh decade, and most people would have retired already many years ago. For now, both Irene and I still like running Borbely Audio, but soon I will need to make that retirement decision. If I have a regret, it would be that I never got back into the pro audio field. I have designed some excellent mike preamps and sold a few kits, which customers claimed were much better than the most expensive commercial ones. However, to succeed in this field you need to offer complete units and a product line, and that wasn't an option at the time. But, as you've heard, I like to talk about audio in all its aspects, and I thank you and Ed Dell for the interest in my work. *audioXpress* is a great magazine, and Ed has done a great deal to further DIY audio. We should recognize that as well.

[JD note: Most of Erno's designs are documented in articles written for *Audio Amateur/audioXpress* magazine, and are reprinted on www.borbelyaudio.com.]



PHOTO 4: An LBAudio/Borbely Audio All-FET line-amp on Teflon PCBs, using Welborne Labs' input selector and attenuator with remote control. (Courtesy LBAudio.)