CLASS-A POWER MODULES

By Erno Borbely

The quest for more pure Class-A power continues. Many listening tests have proven that amplifiers working in "pure" Class A sound better than those in Class AB. Users report an improvement in low-level details and ambience as the bias current increases. They normally attribute this to the fact that the active elements (bipolar and MOSFETs) are operating in their linear region, without abrupt nonlinearities or turn-on/turn-off delays.

I put equal weight on the current capability of Class-A amplifiers. By definition, they are high-current amplifiers, and they are capable of driving difficult speaker loads better than Class-AB amps.

Naturally, the definition of "pure Class A" can be very different from one manufacturer to another. Often this is nothing but marketing hype; the quiescent current is probably high enough to support Class-A operation up to 1W, but nothing more. It is especially disturbing to see claims for Class-A operation up to, say, 50W and then find a tiny heatsink inside the amplifier. Class-A operation requires a great deal of current, consequently generating lots of heat and requiring a very large heatsink. So if you see one with a small heatsink, you can usually question the Class-A operation.

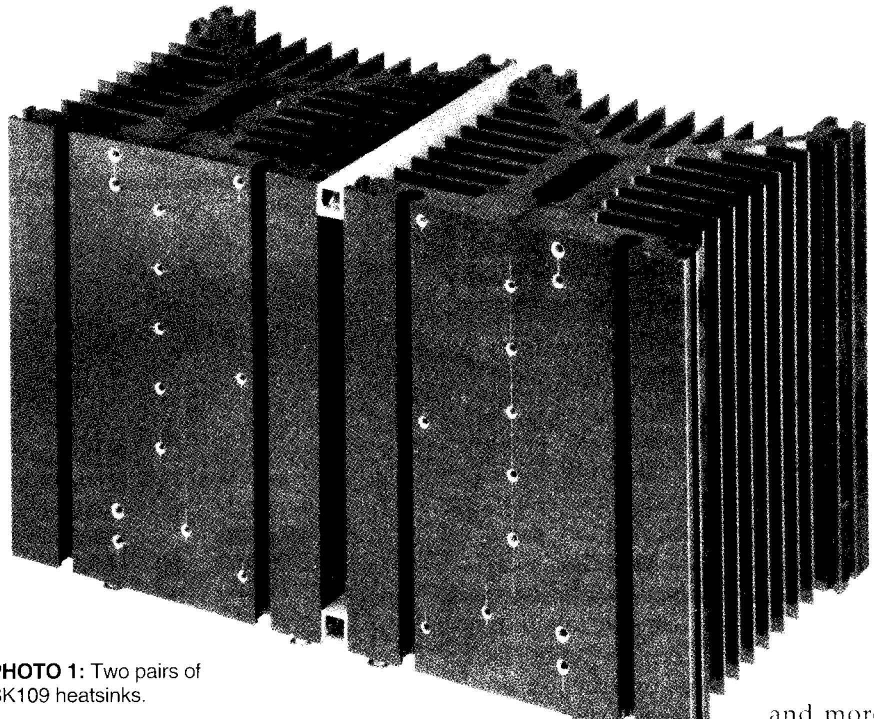

PHOTO 1: Two pairs of SK109 heatsinks.

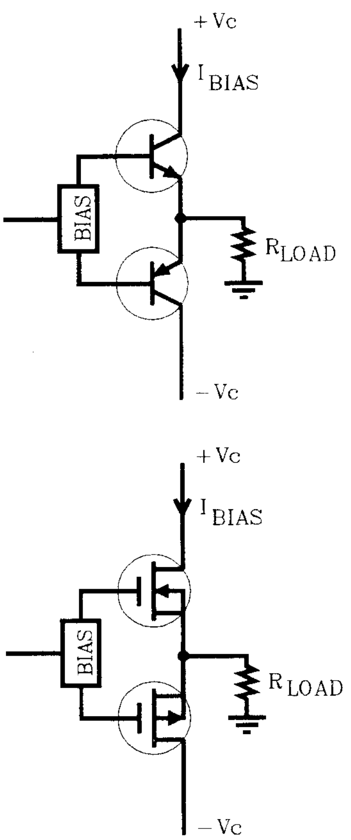

FIGURE 1: The emitter-follower and source-follower stages of a push-pull output stage.

A Short Class-A Primer

The definition of Class A is simply that the device always conducts current and never goes into cut-off. This is especially important to keep in mind when you consider the output stage, where large currents flow. Look at the standard output stage of most power amplifiers (*Fig. 1*)—the push-pull, complementary emitter-follower or source-follower stage. In such an amplifier, the peak output current in Class A is equal to twice the idle or bias current.

Assume that the quiescent or bias current is 1A and you drive the input with a positive-going signal. As the output goes positive, Q1 conducts more and more current, and at the same time Q2 conducts less and less. The peak output current will be twice the quiescent current (i.e., 2A) before Q2 cuts off.

As the Class-A limit depends on the quiescent or bias current, it is important to choose it correctly. Ideally, it should be chosen according to the formula:

$$I_{BIAS} = \tfrac{1}{2}V_C/R_{LOAD} \quad (1)$$

For example, for a supply voltage of ±16V, the bias current should be ½ × 16/8 = 1A. The maximum RMS output

ABOUT THE AUTHOR

Erno Borbely has been employed by National Semiconductor Europe for the last 17 years. He was Manager of Technical Training and worked as a consultant in human resources development. He received an MSc degree in electronic engineering from the Institute of Technology, University of Norway, in 1961, and worked seven years for the Norwegian Broadcasting Corporation, designing professional audio equipment. He has lived in the US and was Director of Engineering for Dynaco and The David Hafler Company. From 1973–1978 he worked for Motorola in Geneva, Switzerland, as Senior Applications Engineer and Application Manager. Mr. Borbely is now taking an early retirement from National and is seeking OEM customers for whom he can design high-end audio equipment. Mr. Borbely's Email address is: BorbelyAudio@t-online.de.

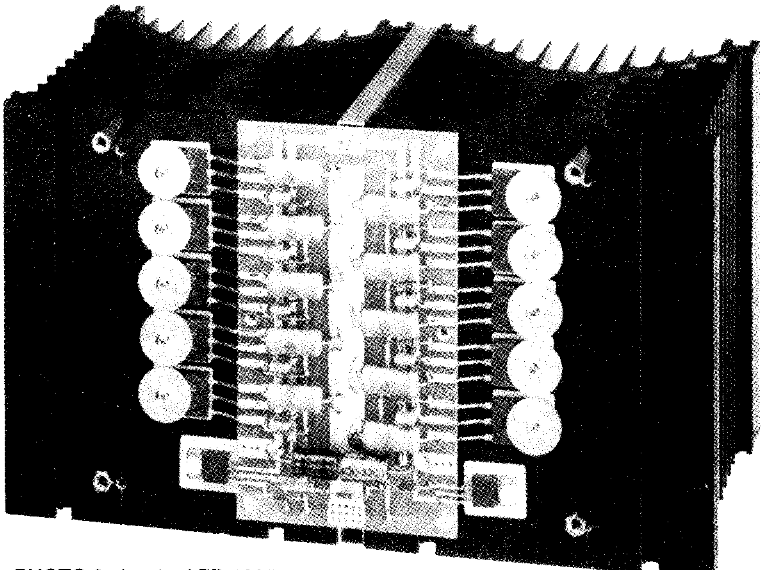

PHOTO 2: A pair of EB-1295s assembled on SK109 heatsinks.

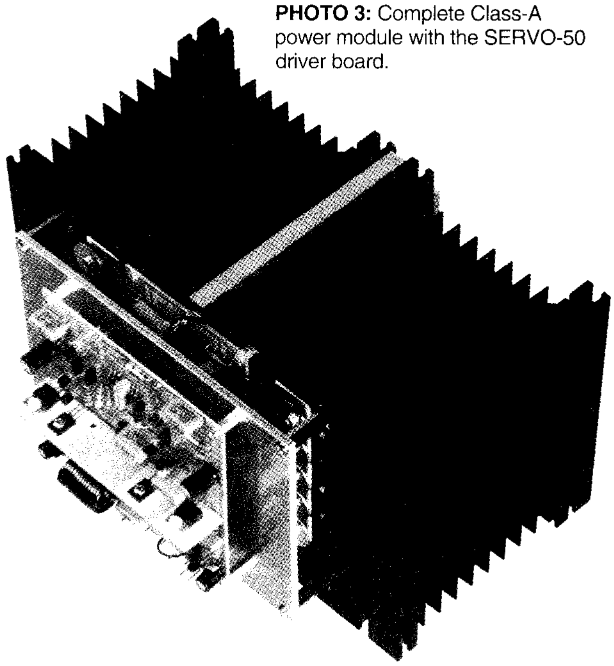

PHOTO 3: Complete Class-A power module with the SERVO-50 driver board.

voltage will be $16/\sqrt{2} = 11.35V$, and the RMS current will be the peak output current divided by $\sqrt{2}$: $2/\sqrt{2} = 1.41A$. The maximum output power is then $V_{RMS} \times I_{RMS} = 16W$. The maximum dissipation in the output stage occurs when idling. It is:

$$P_D = 2 \times V_C \times I_{BIAS} = 32W \qquad (2)$$

Consequently, the maximum efficiency of the Class-A amplifier is 50%.

Using higher voltage will achieve more output power, but not in Class A. The amp will leave Class A when the peak output current exceeds 2A, and

TABLE 1

PARTS LIST: OUTPUT STAGE FOR 50W CLASS-A MONOBLOCK EB-1295/111

RESISTORS	
R1, R7	100
R2–R6, R8–R12	221
R13, R14	82, 1W
R15–R24	0.22, 4.5W
CAPACITORS	
C1–C5, C8–C12	0.1μF, 100V
C6, C7	47μF, 63V
SEMICONDUCTORS	
Q1	2SK216
Q2	2SJ79
Q3–Q7	2SK1529
Q8–Q12	2SJ200
MISCELLANEOUS	
PCB	EB-1295/111 (145 × 145mm)
MOUNTING HARDWARE	
12 × 3mm screws	
10 × 25mm flat washer	
2 × TO-220 10 × TO3P insulator	
6 × 5mm stand-off with 3mm screws	
26 × 1.3mm solder pins	

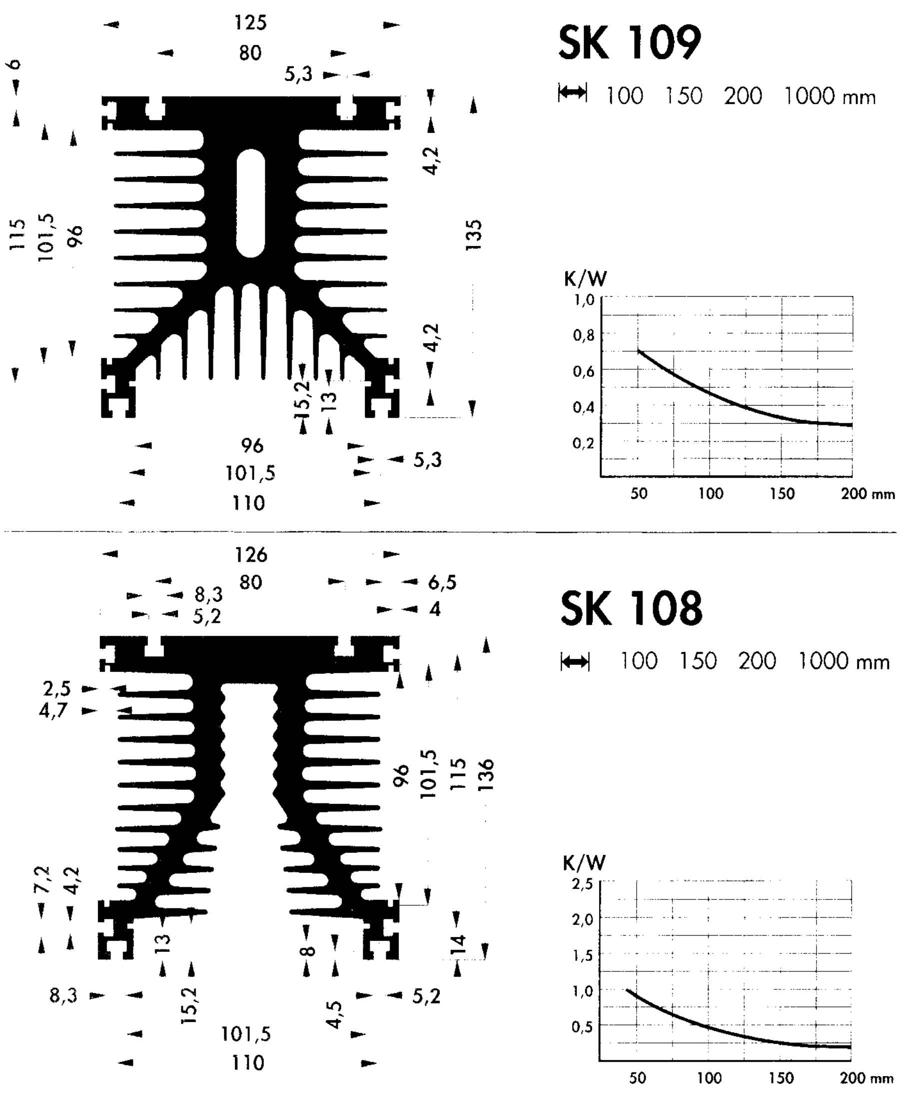

FIGURE 2: Dimensions of the SK108 and SK109 heatsinks.

subsequently will work in Class B. In other words, increasing the supply voltage alone does not increase the maximum Class-A output; you must increase the current as well.

Determining Bias Current

Suppose you wish to make an amplifier that delivers 50W into 8Ω in Class A. How much bias current do you need for it? The RMS output voltage will be:

$$V_{RMS} = \sqrt{P \times R} = 20V\ RMS \qquad (3)$$

This is equivalent to 28.2V peak, so the power supply needs to be a minimum of ±28.2V. Applying the previous calculation to the bias current, you get:

$$I_{BIAS} = \tfrac{1}{2}V_C/R_{LOAD} = 1.76A \qquad (4)$$

The output stage will deliver a peak current of $2 \times I_{BIAS} = 3.52A$ before leaving Class A, which is equivalent to 2.5A RMS. The Class-A output power into 8Ω is:

$$P_O = V_{RMS} \times I_{RMS} = 20 \times 2.5 = 50W \qquad (5)$$

The maximum power dissipation of a 50W Class-A amplifier is:

$$P_D = 2 \times V_C \times I_{BIAS} = 100W \qquad (6)$$

and the efficiency is 50%.

The above calculations are valid for an 8Ω load. For a 4Ω load, since the peak current does not change, the power is limited to:

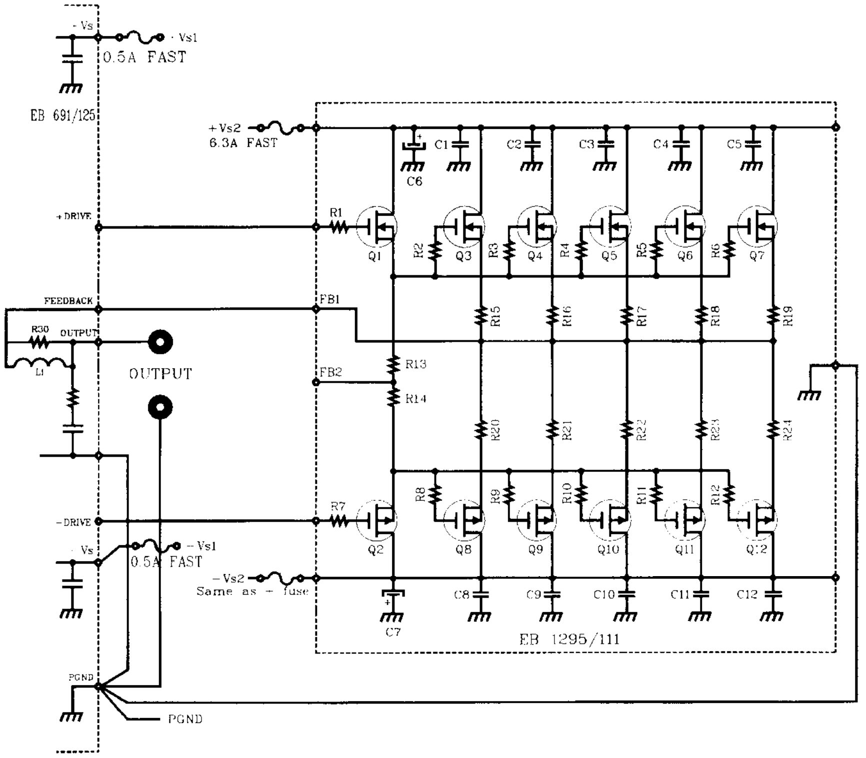

FIGURE 3.1: Output stage for 50W Class-A and 100W Class-AB power amplifiers; operating with global feedback.

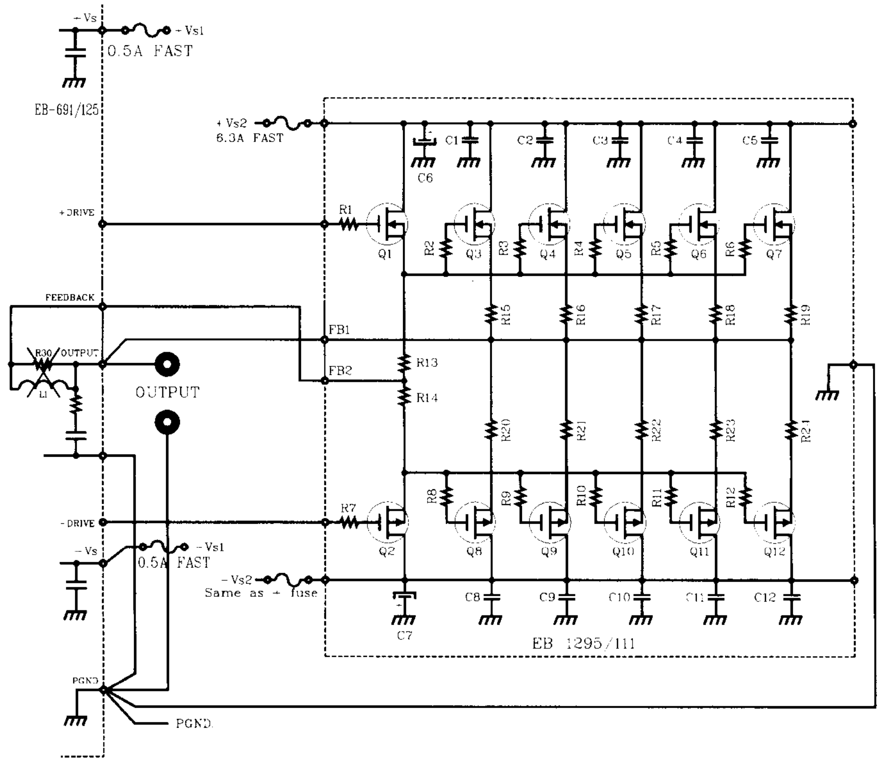

FIGURE 3.2: Output stage for 50W Class-A and 100W Class-AB power amplifiers; operating without global feedback.

TABLE 2

PARTS LIST: POWER SUPPLY FOR 50W CLASS-A MONOBLOCK EB-1196/223

RESISTORS	
R1, R2	4.7k, 4.5W
R3, R4	10k, 1.4W
R5	100k
R6	1.5k
R7	10k
R8, R9	100, 25W (230V) 47, 25W (115V)
CAPACITORS	
C1, C2, C7, C8	0.22µF, 160V, PP
C3–C6	0.1µF, 160V, PP
C9, C10	1000µF, 100V
C11	220µF, 25V, EKR
C12	47µF, 63V, EKR
C13	4.7µF, 35V, TA
C14	0.1µF, 100V
DIODES	
D1–D4	25A, 600V, HFA25PB60 IR 25A, 1000V, BYP101 SIEMENS
D5–D8	2A, 200V, BYV27-200
D9–D12	1.5A, 250V BRIDGE
D13	1N4148
D14	GREEN LED
MISCELLANEOUS	
RY1, RY2	V23037-A401, 12V SIEMENS
Heatsink for TO-3P diodes	SK104, 25mm
F1, F2	Fuse holder with cover 5 × 20mm, 200mA medium
PCB:	EB-1196/223
Mounting hardware	(8 × 3mm screws, insulator for diodes)
DIL 8 socket	
40 × 1.3mm solder pins	
20 × 1mm solder pins	

$$P_O = I_{RMS}^2 \times R_{LOAD} = 25W \quad (7)$$

In other words, the Class-A power into 4Ω will be half the 8Ω value. In order to get the same power in 4Ω, you need to increase the bias current to:

$$I_{BIAS} = 0.705\sqrt{P/R_{LOAD}} = 2.5A \quad (8)$$

These figures assume ideal devices. Although bipolar transistors might come closer to the ideal than MOSFETs, both types require some extra voltage to compensate for the losses. Typically, you'd use 3–5V extra supply voltage. Also, you would normally set the quiescent or bias current higher than the absolute minimum, so that both transistors are still well into the linear region at the maximum output. For this, I usually recommend 20–30% more current.

With a 50W amplifier, you'd probably use a power supply of ±32–35V and run a bias current of 2A, which would result in a power dissipation of 140W! This will, of course, generate a lot of heat, which you must remove to prevent destruction of the transistors. The heatsinks serve this purpose. As Nelson Pass says, heatsinks are the "first-and-foremost" things.[1]

The Heatsinking Problem

Getting rid of the heat is not much of a problem if you can use a fan to blow air over the transistors. Unfortunately, even the quietest fan generates some noise, which is objectionable to most people. Consequently, you need heatsinks with a thermal resistance sufficiently low to get rid of the heat. A number of US manufacturers make suitable heatsinks (Thermalloy, Aavid, and Ahamtor, among others). I use heatsinks from Fischer Elektronik, which has an excellent selection of extrusions in all sizes.

The problem with heatsinks is how to build them into boxes so that they not only get rid of the heat, but also fit mechanically with the rest of the package. The "standard" way is to place one heatsink on each side of a 19″ box, mount the two channels of a stereo amplifier on them, and put the power supply in the middle of the chassis.

This is a task often beyond the abilities of audio amateurs. Some commercial boxes offer "integrated heatsinks" on the sides, and they are certainly easier to fit into your application than doing the whole job yourself. In fact, this is probably the easiest approach when you want to build low- to medium-power stereo amplifiers.

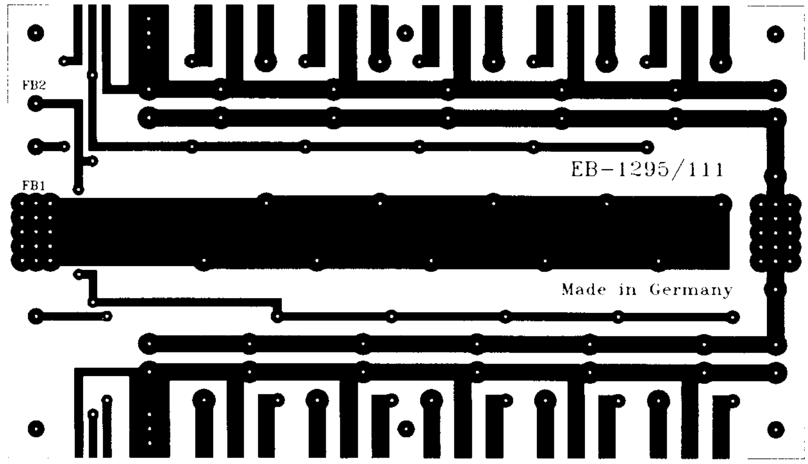

FIGURE 4: Layout for output stage, EB-1295/111; copper side (75% of original).

I prefer to make my Class-A amplifiers in monoblocks, so I can place them close to my speakers. For these, I have found no commercial boxes. Some Japanese products have the heatsink, albeit very small, inside the box. Obviously, you can also use this approach for amateur projects, even if the heatsink is significantly larger than in the Japanese models.

Determining Heatsink Size

You can calculate the size of the heatsink according to the necessary thermal resistance. When you know the maximum dissipation and temperature you

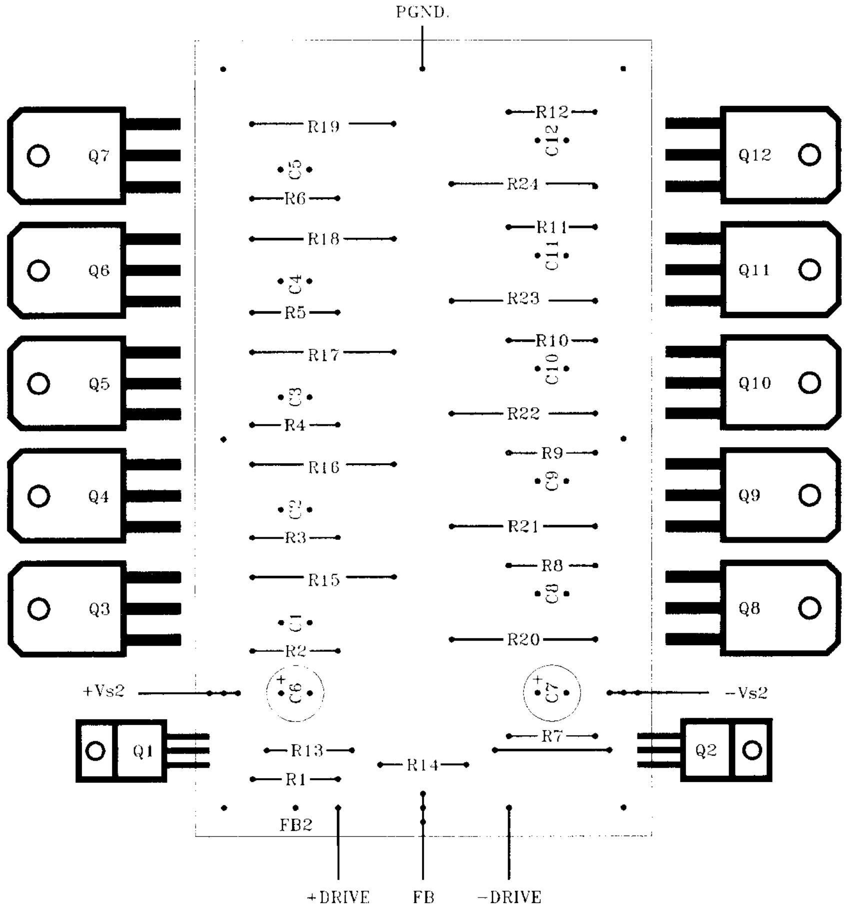

FIGURE 5: Stuffing guide for Class-A output stage, EB-1295/111 (75%).

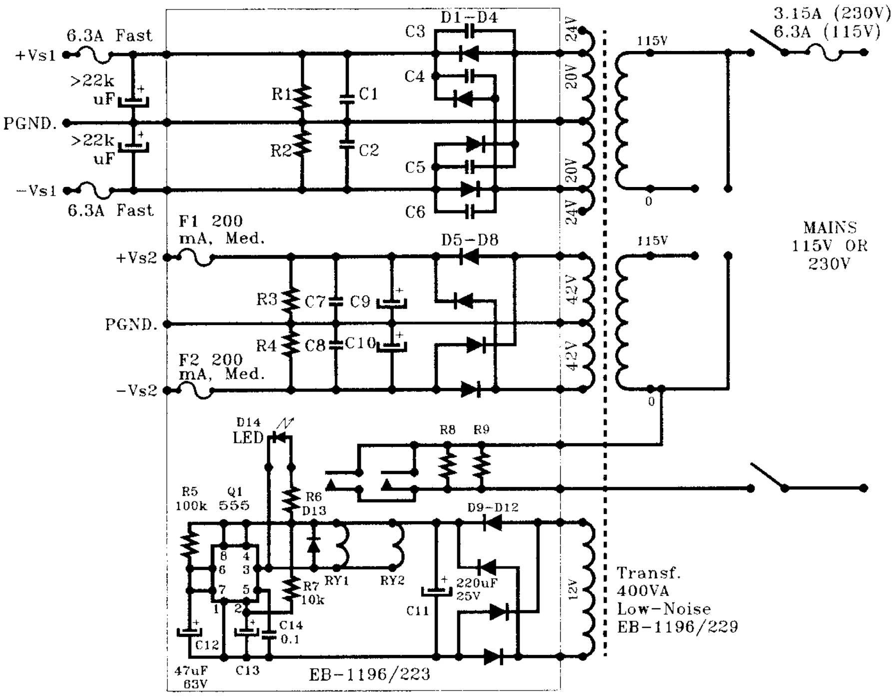

FIGURE 6: Power supply for 50W class-A monoblock.

wish to allow on the heatsink, the thermal resistance is given by:

$$R_{TH} = (T_{MAX} - T_{AMB})/P_D \qquad (9)$$

I consider 60°C to be the absolute maximum on the heatsink; 55° is preferable, since that is already very hot to the touch. The ambient temperature is usually assumed to be 25°. If you want to dissipate, say, 150W, the thermal resistance must be:

$$R_{TH} = (55 - 25)/150 = 0.2kW \qquad (10)$$

Two models suitable for such a dissipation are the SK108 and 109 (*Fig. 2*) from Fischer Elektronik. The SK109 is very similar in shape and dimensions to the AHAMTOR #5315. Fischer Elektronik delivers these in lengths of 100, 150, 200, and 1000mm. I suspect that these types were originally meant to be used with fans, but if you use them vertically, with good air flow, they have a very low thermal resistance.

Using two of them per channel results in a thermal resistance of approximately ½. For a 150mm section of the SK109, the thermal resistance is about 0.35k per watt, so two of them will give you less than 0.2k per watt. If you use 200mm sections, the thermal resistance will go down to 0.15k per watt, and you can dissipate close to 200W.

The actual value of the thermal resistance depends on a number of factors related to the air flow: where and how the heatsinks are mounted, where the amplifier is placed, and so on. It is advisable to avoid overestimating the capabilities of the heatsinks in terms of power dissipation.

The calculation of formula (10) yields only the temperature on the heatsink, not on the transistor chip itself. The chip's temperature depends on the thermal resistance of the insulation between the transistor and the heatsink, as well as that of the transistor package itself. Since I use a number of transistors in parallel, the dissipation is spread over all of them, and using thermally conducting silicon insulation keeps the temperature on the chip well below the maximum allowed even with TO-3P packages.

A Practical Class-A Power Module

Borbely Audio offers a Class-A power module that you can build into just about any box of suitable dimensions. The monoblock is made up of two 150mm-high SK108 or SK109 heatsinks, mounted together with 10mm-square aluminum tubes (*Photo 1*), which I am using as feedthrough for the power-supply cables.

The output stage is mounted vertically. All N-channel MOSFETs are mounted on one of the heatsinks, and the P-channel ones on the other (*Photo*

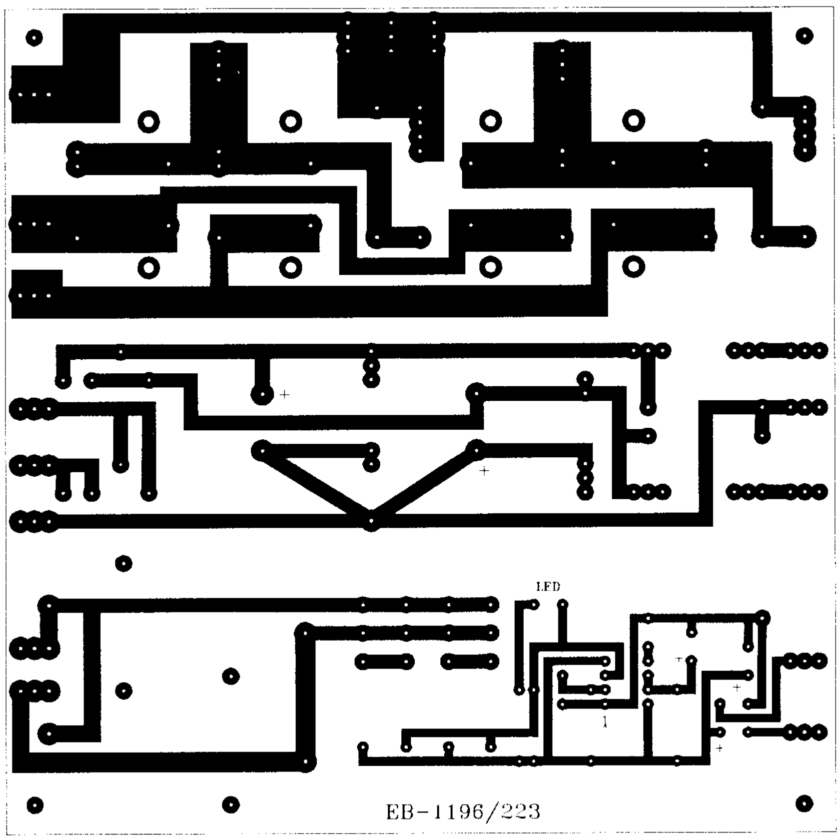

FIGURE 7: Power supply for servo 50, EB-1196/223; copper side (75%).

You can order the Borbely Audio Class-A MOSFET Power Module in the following versions:

1. 2 pairs (4 pieces) of SK109 heatsinks, drilled and assembled, black anodized, 150mm high (*Photo 1*).
2. 1 pair of EB-1295/111 output stage in kit form, with 5 pairs of 2SK1529/2SJ200 10A MOSFETs each and drivers.
3. 1 pair of EB-1295/111 assembled on 1 (*Photo 2*).
4. 1 pair of 19″ boxes in kit form: black, 4 units high, 442mm wide, 270mm deep (perforated, but not drilled for kit).
5. 1 pair of power supply EB-1196/223 with 25A HEXFRED/FRED diodes, driver supply, and slow-turn-on circuit.
6. 1 pair of mains transformers, 400VA low-noise toroid, 115/230V, 50/60Hz, approximately 4.2kg each.

2). The output board is mounted on 5mm standoffs, and the MOSFETs directly on the heatsinks, with silicon-rubber insulation. I use large, round, flat washers for mounting the output MOSFETs, since these give an even pressure on the TO-3P packages, thus ensuring low thermal resistance. Input to the output stage is on the bottom of the module.

Photo 3 shows a complete Class-A power module with the SERVO-50 driver board. The driver board is mounted on an aluminum plate that shields it from the output board. This is necessary to avoid distortion at high frequencies caused by the high currents in the output stage.

The input of the driver board is at the top of the picture, the output at the bottom, and the connections between the two boards are also at the bottom. Power-supply connections and output are at the bottom. I make use of the lower aluminum tube for the power-supply connections.

Power-Module Mounting

An advantage of the power module is that you can mount it on any flat chassis. *Photo 4* shows such a chassis, which is part of a 19″ box that's available in kit form. The perforations on the chassis are essential for the air flow. Although not shown, it is advisable to mount the module on 5mm standoffs to create more space for air to flow around the bottom of the heatsinks. If you have a mechanical shop and can make your own chassis, you might consider a two-piece model, one for the driver/output part and the other for the power supply, leaving the heatsink completely free for optimum air flow.[2]

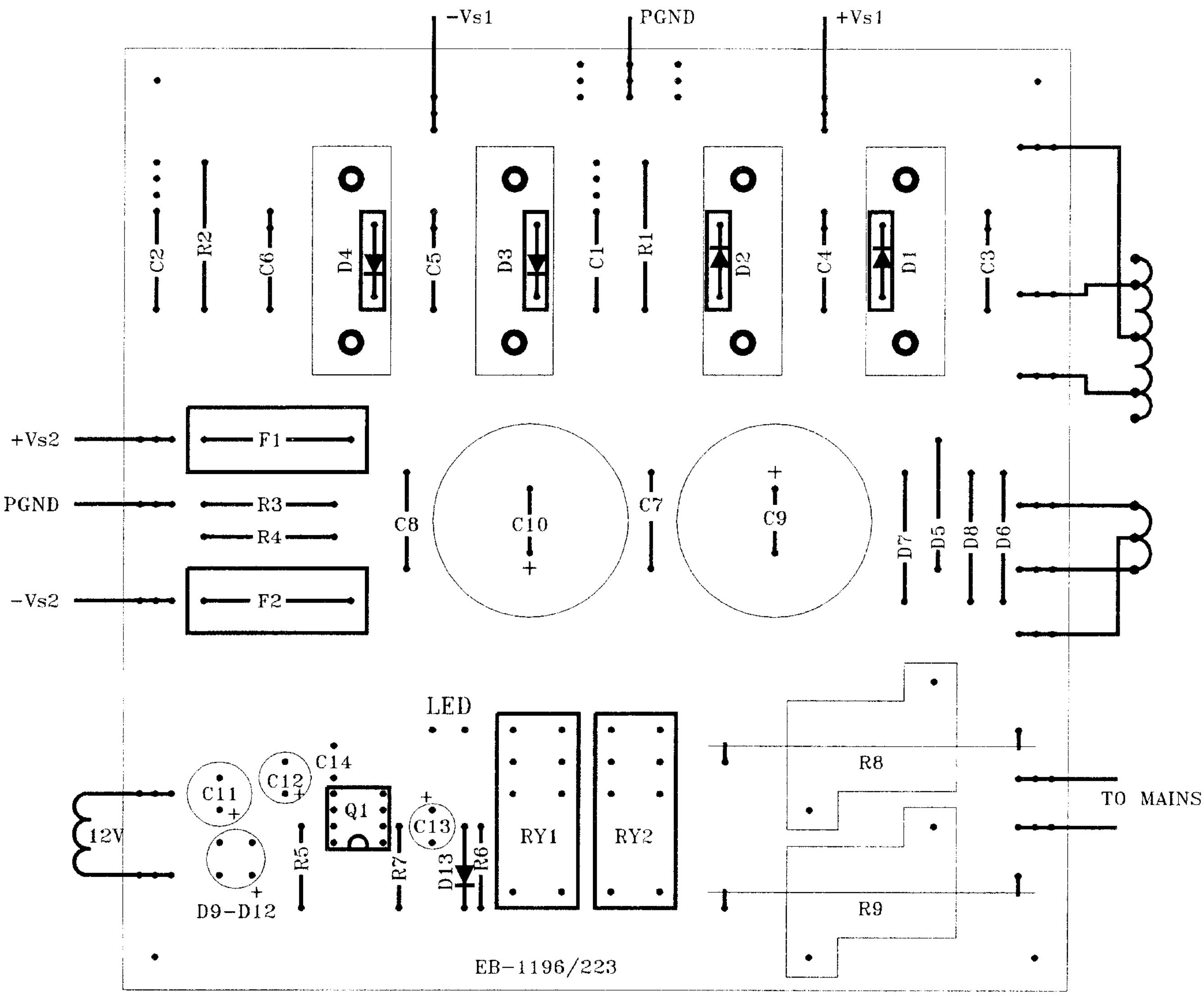

FIGURE 8: Stuffing guide for power supply, EB-1196/223.

Photo 5 shows the complete amplifier mounted in the above-mentioned 19" box. The power module is shown in the right-hand side of the box, and the transformer, filter caps, and power-supply board on the left-hand side. A further advantage of this layout is that the massive heatsink lies between the power supply and the driver boards, resulting in less possibility of hum-pickup from the massive power transformer.

I use 4 × 22000 µF/63V high-quality, low-ESR RIFA electrolytics in the power supply, and I screw the power-supply board directly to the top of the electrolytics, eliminating the wire connections. The fuses for the high-current supply are mounted on top of the board.

The power-supply board also includes the four 25A HEXFRED soft/fast recovery diodes for the high-current supply (shown with heatsinks), the power supply for the driver board, and a delayed turn-on circuit to avoid the inrush current when you switch on the unit. (Note that the production version of the power-supply board is smaller and is connected to the electrolytic caps by wires, so that you can choose other types of caps if you wish.)

The transformer is a 400VA low-

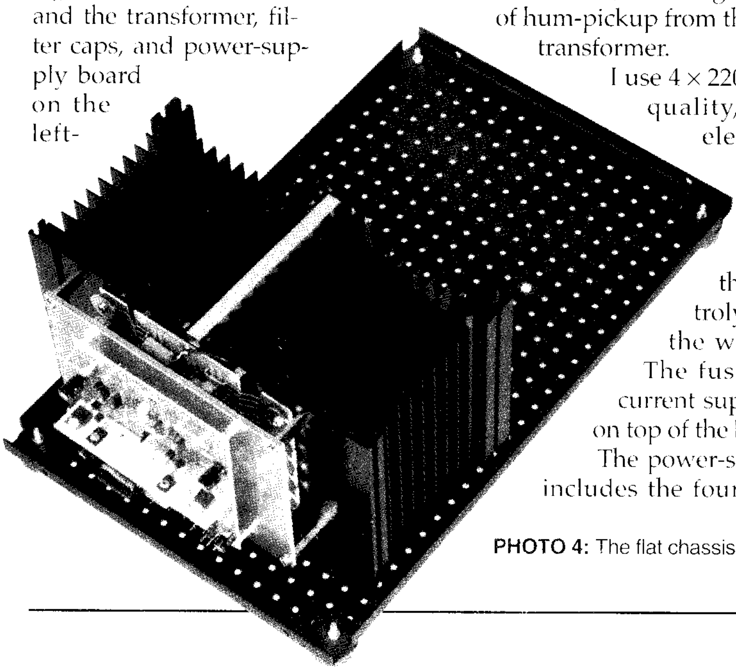

PHOTO 4: The flat chassis.

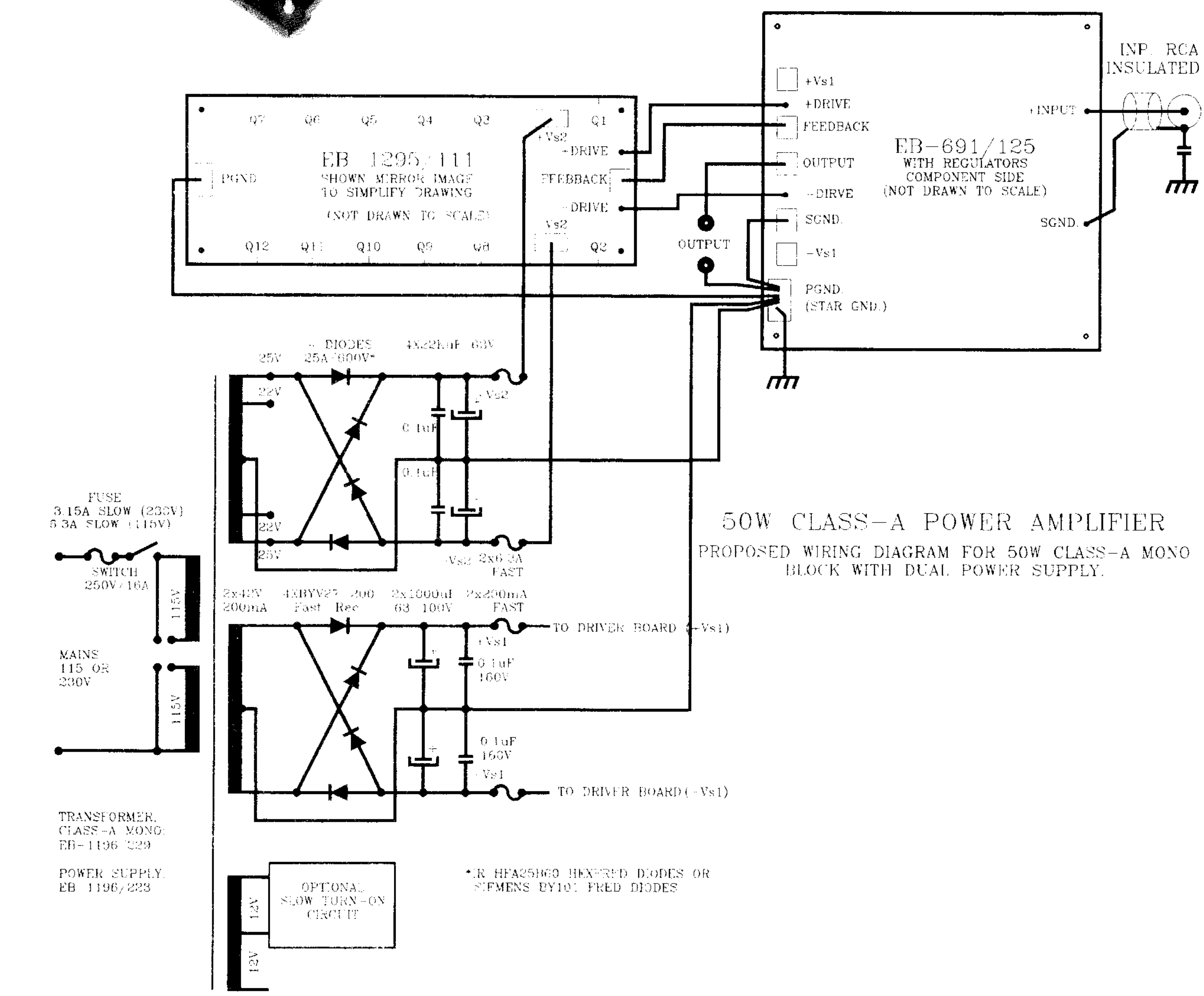

FIGURE 9: Wiring diagram for 50W Class-A power amplifier.

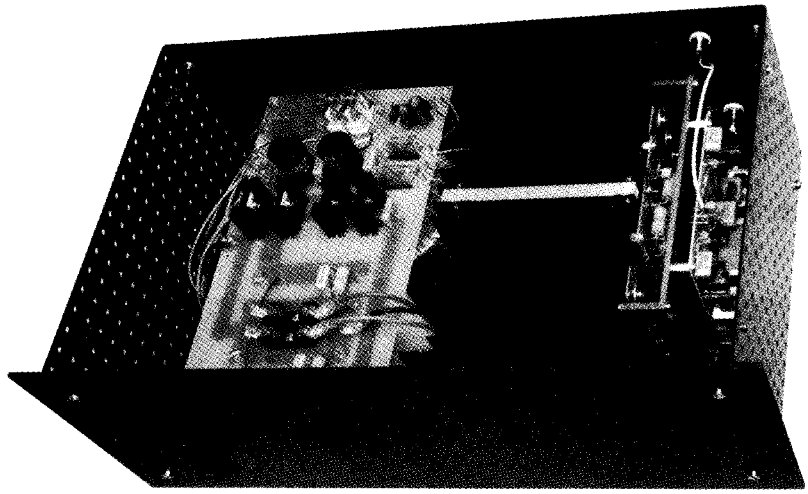

PHOTO 5: The complete amp mounted in the 19″ box.

noise toroid design, weighing 4.5kg. Although not shown, the top plate of the box is also perforated—again, essential for good air flow.

Softening the Sound

Figures 3.1 and *3.2* show the schematic of the output stage, EB-1295/111 (*Photo 2*). Normal feedback is shown in *Fig. 3.1*, while in *Fig. 3.2* the output stage has been removed from the global feedback loop, which many will consider an advantage, since it "softens up" the sound of the amplifier. Note that the global feedback is now taken from the split-source resistors R13 and R14 between Q1 and Q2, and the servo, if used, also senses this point.

Figure 4 is the layout of the output stage, and *Fig. 5* is the stuffing guide. I incorporated source resistors into the layout to alleviate the current sharing between the MOSFETs. You can omit these if the MOSFETs are matched.

Figure 6 shows the schematic of the power supply EB-1196/223. Naturally, you can also use this supply for Class-AB amplifiers. The slow-turn-on circuit switches out the resistors after about ten seconds. The power-supply layout and stuffing guide appear in *Figs. 7* and *8*, respectively.

Figure 9 is the proposed wiring diagram for the 50W Class-A monoblock, using the output stage and the power supply described above. The driver board shown is the SERVO-50 (EB-691/125). For details, see Fig. 1, *TAA* 3/93, p. 9. Or you can use other Borbely Audio drivers. Finally, *Figs. 10* and *11* show the drilling schedule for the heatsink assembly and mounting plate. ■

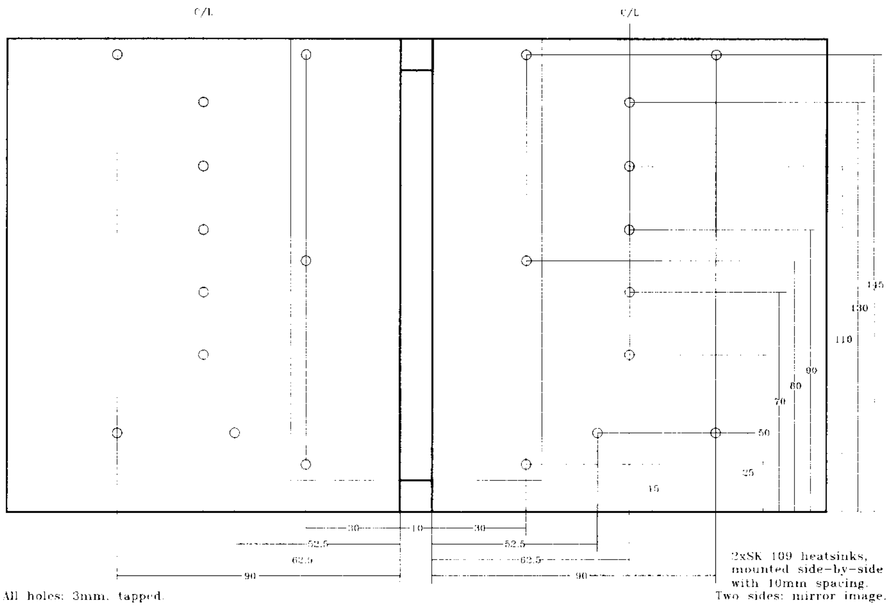

FIGURE 10: Drilling of heatsink assembly for EB-1295/111.

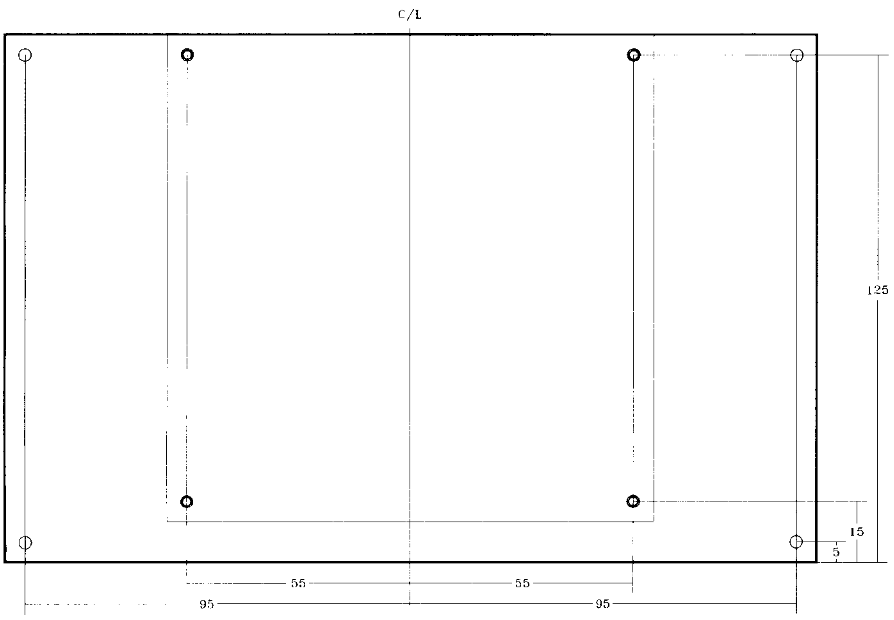

FIGURE 11: Mounting plate for heatsink assembly.

ACKNOWLEDGMENTS:

My sincere thanks to Nelson Pass for his comments on the Class-A operation of complementary emitter/source followers. As usual, I am indebted to Dr. Kalman Molnar, who puts my intuitive fancies on a solid mathematical ground; to Steve Setescak, with whom I discussed mechanical packaging of power amps; and last, but not least, many thanks to our friend Josef Peintner, for his excellent photographs.

REFERENCES:

1. Norman Thagard and Nelson Pass, "Build the A75 Power Amplifier, Part II," *TAA*, 1/93.

2. Steve Setescak, private communication.

3. Erno Borbely, "New Power Amp Modules, Parts I and II," *TAA* 3/93 and 4/93.