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Volume 8 *Number 5*
1996

READING GLASS

Audio Amateur readers, no doubt, are aware of the design talents of **Erno Borbely**, who has contributed many high-quality amp designs to *Audio Amateur & Electronics* magazine. Now, the German author showcases his magic in these pages with a single-ended design (also available from the author as a kit)

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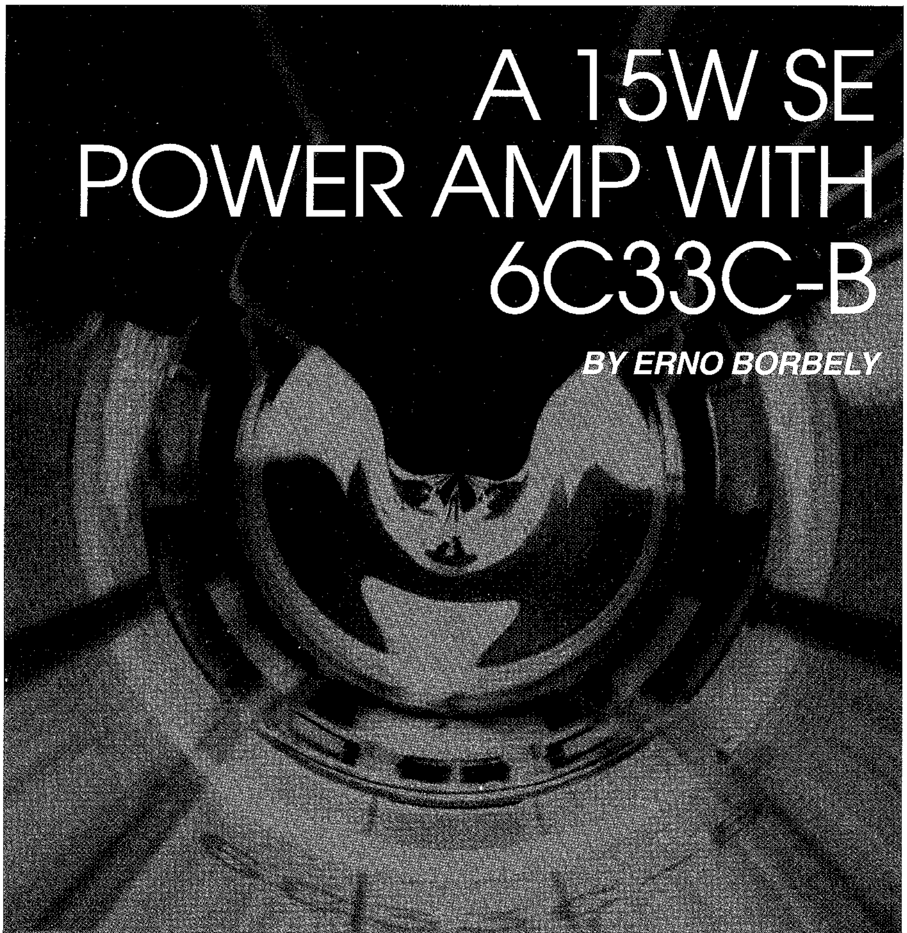
$6.00

GLASS AUDIO

A 15W SE POWER AMP WITH 6C33C-B

BY ERNO BORBELY



I was not at all sure about getting into single-ended (SE) tube amps, because the choice of available tubes was limited. I do not like any of the high-efficiency speakers, and those with lower efficiency all require more than the meager 3W or 6–7W that the 2A3 or 300B SE amps, respectively, can deliver. Granted, there are 211s and 845s on the market that can drive just about anything, but, frankly, I am afraid of voltages higher than 350–400, and more than 1000V scares the hell out of me.

I have, however, found some interesting tubes that operate with reasonable voltages, among them the Russian 6C33C-B triode (*Photo 1*). Aside from its ability to deliver quite a lot more than the 2A3s, and to work off manageable supply voltages, it is also a work of art. Despite its consuming so much power that I can use it as a room heater on cold Bavarian winter nights, it inspires confidence because it is built like a battleship, with features found only in military gear, including thick glass and inter-

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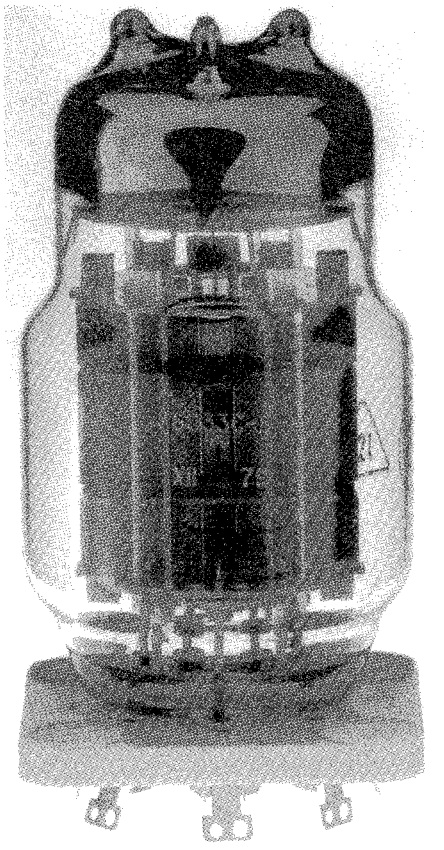

PHOTO 1: 6C33C-B tube.

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nal bracing to withstand vibrations. And the 15W certainly gives some hope that it can make less efficient speakers worth listening to.

The 6C33C-B Triode

Originally designed as a series element in voltage regulators for stationary and mobile equipment, the 6C33C-B is a large tube. Its greatest diameter is 65mm, and it is 130mm tall. It has two filaments and two cathodes. You can connect the two 6.3V/3.3A filaments in parallel or in series, consuming a total of 42W! Maximum anode dissipation is 45W with one cathode operating, and 60W with both.

The maximum anode voltage is 250V when the anode dissipation is more than 30W, and 450V when it's less than 30W. Due to the high filament and anode dissipation, the tube runs very hot (260°C), so you can use it only with ceramic sockets. You should also drill holes around the socket for increased ventilation.

The 6C33C-B has a transconductance of 39mA/V, a mu of less than 4, and a very low plate resistance of about 100Ω. The anode characteristics are shown in *Fig. 1*. Due to its unique characteristics, the tube is well suited for audio use, but you need to use transformers with primary impedances that are much lower than conventional ones (*Photo 2*). In SE mode, the primary impedance of the transformer is about 600Ω; in push-pull amplifiers, it is 1–1.2kΩ.

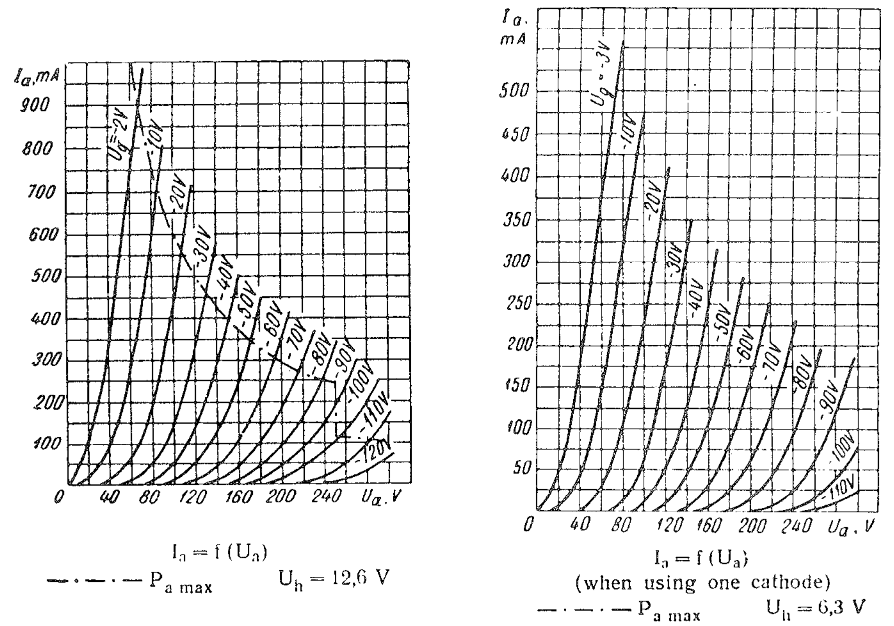

FIGURE 1: Anode characteristics of the 6C33C-B.

Fixed Bias or Cathode Bias

The basic circuits for operating the 6C33C-B in SE mode with fixed bias and cathode bias are shown in *Figs. 2a* and *2b*. Although the two circuits are similar in performance, the cathode-bias circuit requires a higher supply voltage, with approximately 15W dissipated in the cathode resistor, and it yields slightly less power and has worse distortion than the fixed-bias circuit. Its advantage is the simpler power supply, because you don't need a bias circuit.

I chose an anode voltage of about 200 and an anode current of 220mA for both circuits. Though I operate the 6C33C-B with both filaments (and consequently both cathodes), I selected an operating point that results in 44W anode dissipation. This is just a bit more than two-thirds of the maximum, thus ensuring longer tube life. With the 600Ω output transformer, this yields about 15W. If you wish to push the tube closer to its limits, you could probably get 18–20W output.

A Simple SE Amplifier

The 6C33C-B needs a very large voltage swing at the input to produce this output. Measurements show that approximately 55V RMS are needed to drive it. The simplest circuit that can produce such a voltage swing with reasonable distortion is shown in *Fig. 3*. Half of the

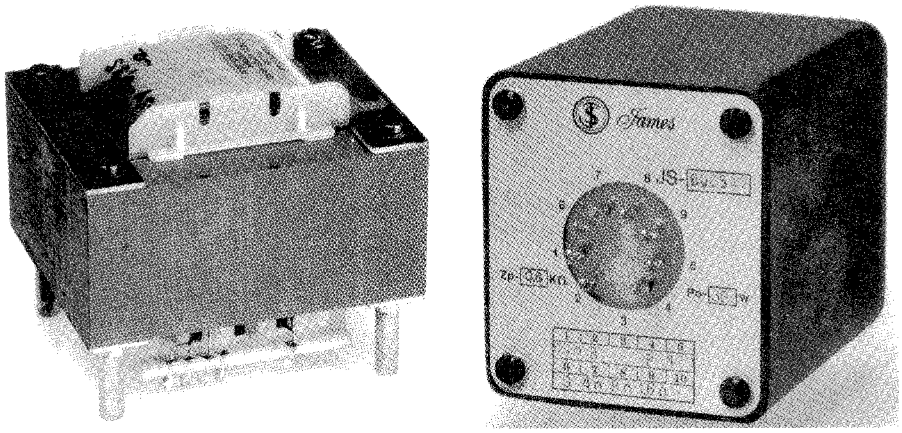

PHOTO 2: Two transformer prototypes for the 6C33C-B-based power amp: the open-frame transformer (left) by Johan Bernstrøm of Sentec (Sweden) and the potted version by James Wu of Taiwan (right).

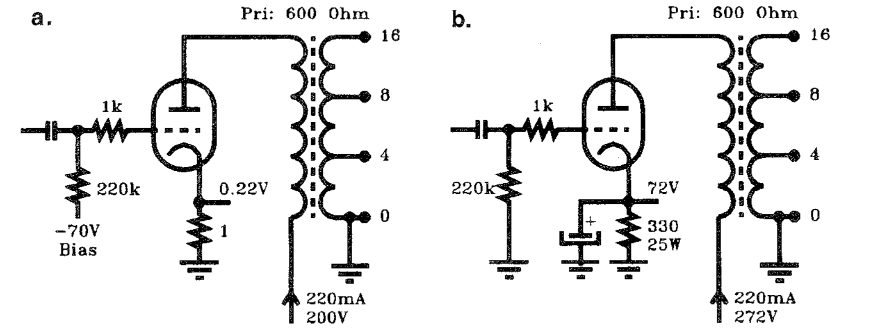

FIGURE 2: Basic circuits for the 6C33C-B in SE mode: a) fixed bias; b)cathode bias.

TABLE 1

DISTORTION MEASUREMENTS

OUTPUT VOLTAGE ACROSS 8Ω	OUTPUT POWER INTO 8Ω	DISTORTION WITHOUT CANCELLATION	DISTORTION WITH CANCELLATION
1V RMS	0.125W	0.5%	0.15%
2V RMS	0.5W	1%	0.3%
4V RMS	2W	2%	0.8%
8V RMS	8W	4.2%	2%
10V RMS	12.5W	6.5%	3.5%
11V RMS	15.125W	10%	6%

6SN7GT/6H8C is operated in grounded cathode configuration, while the other half is used as a cathode follower. The frequency response of the driver circuit is several hundred kHz. The gain is low, and it needs 3.5V RMS to drive the 6C33C-B. *Table 1* shows distortion as a function of output voltage across an 8Ω load.

The distortion, which is predominantly second harmonic, is, as expected, not very impressive. But again, that is probably the very reason that some of you like the sound of the SE amplifiers. As far as I am concerned, I like tube sound, but I don't necessarily like the several percent of distortion of any kind. You can't use feedback, which would help to linearize the circuit, because it does not have enough open-loop gain.

Distortion Cancellation

Instead of feedback, I am using distortion cancellation[1] by permission of Johan Bernstrøm of Sentec AB in Sweden, who says that this technique is not used much nowadays, although it is ideal for SE amplifiers. A simple version of this is shown with dotted lines in *Fig. 3*.

The resistor and trimpot load the anode circuit of the 6SN7GT/6H8C and predistort the signal. Since this is 180° out of phase with the 6C33C-B output, the distortion in the 6SN7GT/6H8C and the 6C33C-B tend to cancel each other. The distortion with cancellation is also shown in *Table 1*. Obviously, the cancellation is not 100%, but the distortion is significantly better than without it, especially at lower levels.

The output impedance of the amplifier, measured on the 8Ω output, is 2.8Ω;

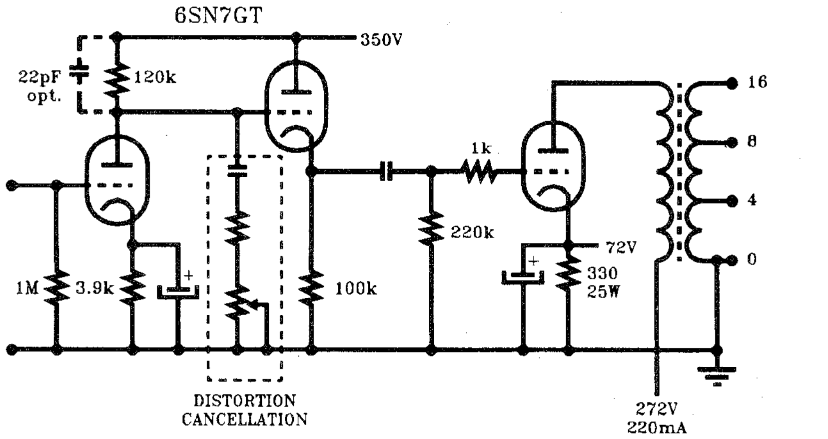

FIGURE 3: Simple SE power amplifier with cathode bias.

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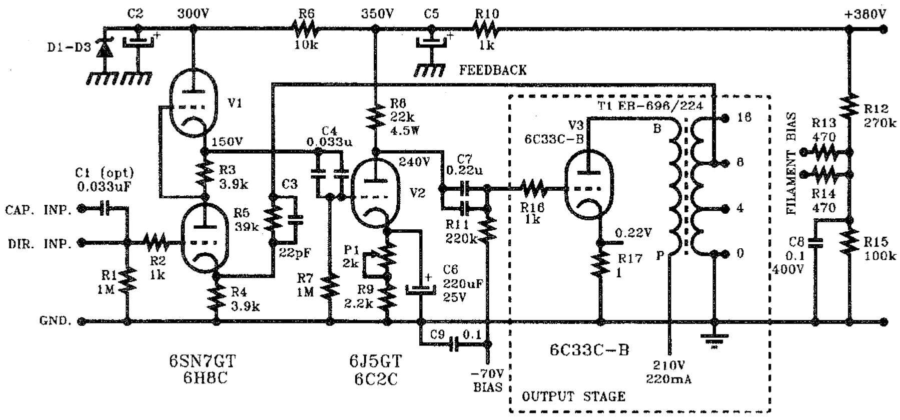

FIGURE 4: Amplifier with distortion cancellation and optional feedback.

TABLE 2

DISTORTION FROM FIG. 4

OUTPUT VOLTAGE ACROSS 8Ω	OUTPUT POWER INTO 8Ω	DISTORTION WITH BUILT-IN CANCELLATION	DISTORTION WITH OPTIONAL FEEDBACK
1V RMS	0.125W	0.06%	0.02%
2V RMS	0.5W	0.13%	0.043%
4V RMS	2W	0.38%	0.125%
8V RMS	8W	1.4%	0.48%
10V RMS	12.5W	2.2%	0.78%
11V RMS	15.125W	2.8%	1%
12V RMS	18W	3.3%	1.6%
13.5V RMS	22.7W	10%	10%

TABLE 3

PARTS LIST FOR 6C33C-B DRIVER BOARD EB-396/225

RESISTORS		
R1, R7	1M	
R2	1k	
R3, R4	3.9k	
R5	39k	
R6	10k, 4.5W	
R8	22k, 4.5W	
R9	2.21k	
R10	1k, 4.5W	
R11	221k	
R12	270k, 1.4W	
R13, R14	470, 1.1W	
R15	100k, 1.4W	
All resistors 0.5W, 1% Metalfilm, or Tantalum, unless otherwise noted.		
TRIMPOT		
P1	2k, 0.5W	CERMET, ROE CT–9W
CAPACITORS		
C1 (opt.)	0.033µF/400V	WIMA MKP–10
C2	10µF/450V	
C3	22pF/160V	PS
C4	0.033µF/400V 1000pF/630V	WIMA MKP–10 in parallel with Siemens PP
C5	47µF/450V	Siemens
C6	220µF/25V	ROE/FROLYT EKR
C7	0.22µF/400V 1000pF/630V	WIMA MKP–10 in parallel with Siemens PP
C8	0.1µF/400V	WIMA MKP–10
C9	0.1µF/160V	RIFA PP
TUBES, DIODES		
V1	6SN7GT/6H8C	
V2	6J5GT/6C2C	
D1, D2, D3	100V, 1W zener	
MISCELLANEOUS		
20 × 1mm solder pins		
PCB: EB–396/225		
8-pin OCTAL Sockets		

i.e., the damping factor is 2.85. This is very low, and the loudspeaker needs to have a constant impedance versus frequency, otherwise the overall frequency response will be nonlinear. Wideband loudspeakers will probably work very well with this high-output impedance, but complex, multiway speakers will have problems. You can reduce the output impedance by applying negative feedback around the amplifier. However, to apply feedback, you need more gain in the driver, and the simplest way to get it is to add a predriver.

Two-Stage Driver

Figure 4 shows a fixed-bias 6C33C-B amplifier with a two-stage driver, which can also be used with the cathode-bias output. The input stage is a series-connected 6SN7GT/6H8C with very good linearity and low output impedance. The latter is necessary because of the rather high input capacitance of the 6SN7GT.

The second stage is a grounded cathode amplifier with a 6J5GT/6C2C triode and built-in distortion cancellation. The principle is the same as described earlier, but this time you build the cancellation into the amplifier by changing the DC operating point of the 6J5GT tube. The adjustment requires a distortion analyzer and is done with P1. If you don't have one, replace the trimpot with a jumper. Distortion will not be as low as with the cancellation adjustment, but certainly will be close enough to work well.

You will notice that I have removed the cathode follower from the driver. I know that most published 6C33C-B circuits use a cathode follower to drive the 6C33C-B. Some of them even DC-couple the cathode follower to the 6C33C-B, which is, of course, necessary if you want to drive it with grid current. However, that was not my intention here; in fact, I wanted to prevent the 6C33C-B from going into that condition. On the other hand, it is true that the 6C33C-B has some input capacitance that has to be charged and discharged by the driver, but this can also be done with a grounded cathode amp, if it has enough current drive capability.

The distortion of the amplifier in *Fig. 4* is shown in *Table 2*. It has been minimized at 4V RMS output. Again, the cancellation is not 100%, but now you have enough open-loop gain in the complete amplifier to apply a small amount of feedback around it and reduce the distortion further.

TABLE 4

PARTS LIST FOR OUTPUT STAGE

RESISTORS	
R16	1k
R17	1, 4.5W
TUBES	
V3	6C33C–B
TRANSFORMER	
T1	EB–696/224
MISCELLANEOUS	
Tube socket for 6C33C–B	

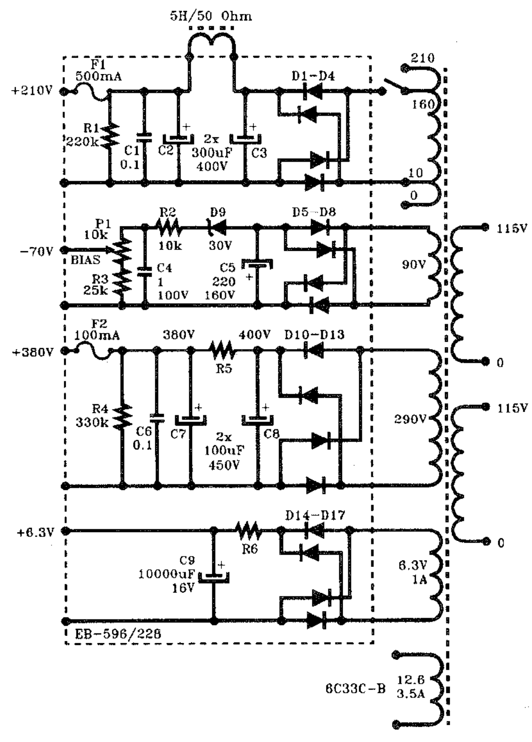

FIGURE 5: Power-supply schematic.

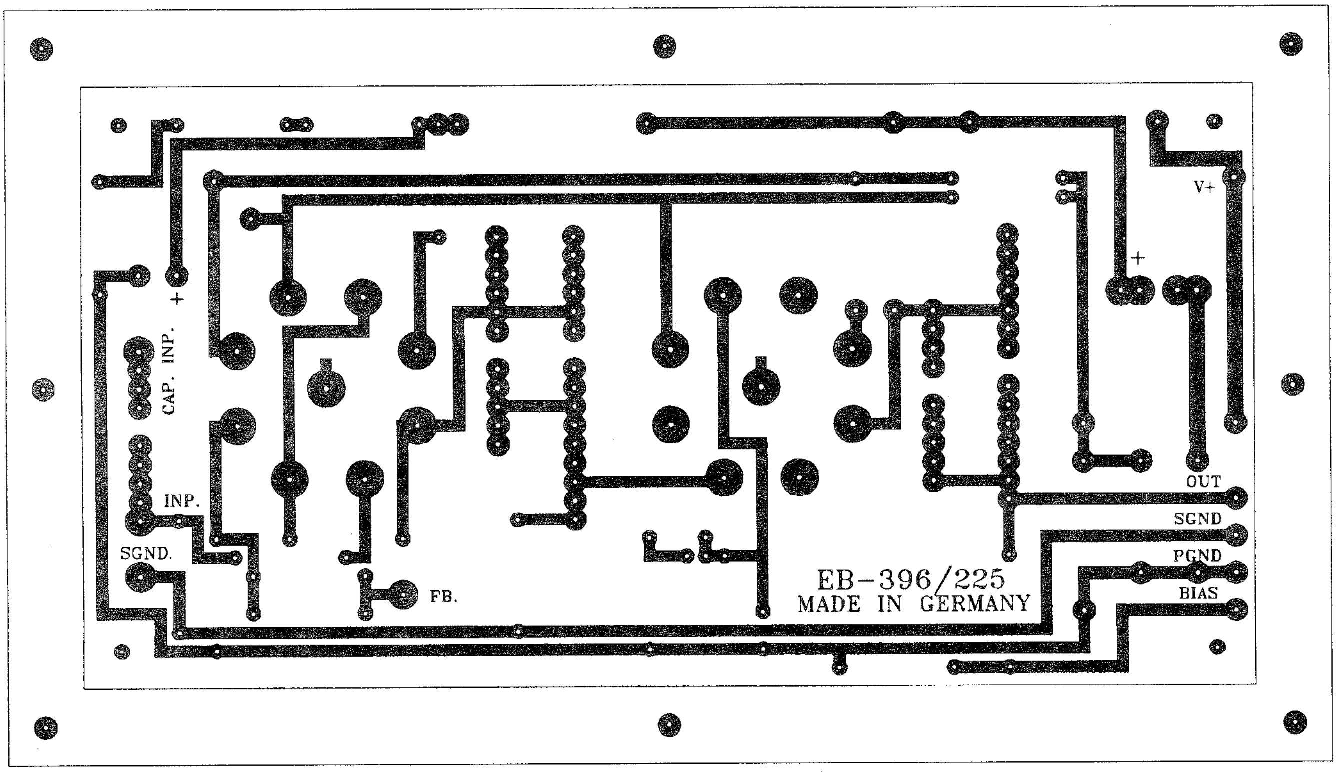

FIGURE 6: Driver for SE power amp (1:1).

Adding a Bit of Feedback

The maximum output of the amplifier with 10% THD has increased to over 20W. The open-loop gain is 23.1 times (27.3dB), and it now needs 0.476V RMS to drive it to 15W. The output impedance has not changed with the two-stage driver circuit, but you can apply feedback to reduce it. The feedback is going from the 8Ω output to the cathode of the input stage.

As you now have an extra 180° phase shift in the chain, you must reverse the primary taps of the output transformer to get the right phase for the feedback. The feedback reduces the gain to about 7.3 times (17.3dB), so it is approximately 10dB. The input voltage is 1.5V RMS for 15W output.

The feedback has reduced the distortion further, as indicated in *Table 2*. The output impedance decreased to 0.6Ω, with a damping factor of 13.3 times, which is probably enough to work with most commercial speakers.

Rise time for the feedback amplifier is 4μs at 10V peak-to-peak output voltage. Frequency response without feedback is −3dB at 50kHz; with feedback, it increases to −1dB at 100kHz. The amplifier's power bandwidth with the EB-696/224 transformer is 40Hz–20kHz without feedback.

Because of the wide bandwidth of the *to page 48*

TABLE 5

PARTS LIST FOR POWER SUPPLY BOARD EB-596/228

RESISTORS		
R1	220k, 1.4W	Metal oxide
R2	10k, 0.5W	Metal film
R3	25k, 0.5W	Metal film
R4	330k, 1.4W	Metal oxide
R5	1k, 4.5W	Metal oxide
R6	0.22, 4.5W	Adj. for 6.3V.
TRIMPOT		
P1	10k, 0.5W	CERMET, ROE CT-9W
CAPACITORS		
C1, C6	0.1μF, 400V	WIMA MKP-10
C2, C3	300μF, 400V	Siemens
C4	1μF, 100V	ROE MKT-1826
C5	220μF, 160V	ROE EKO
C7, C8	100μF, 450V	Siemens
C9	10,000μF, 16V	Siemens
DIODES		
D1, D2, D3, D4	BYT13–1000	3A, 1kV
D5, D6, D7, D8	KB-10,	1.5A, 250V Bridge
D9		30V, 1W zener
D10, D11, D12, D13	BYT11–1000	1A, 1kV
D14, D15, D16, D17	11DQ10,	1.1A, 100V, Schottky
MISCELLANEOUS		
F1	Fuse holder	Wickman, 19646 holder, 19648 cover
	Fuse: 500mA	Medium
F2	Fuse holder	Wickman, 19646 holder, 19648 cover
	Fuse: 100 mA	Medium
40 × 1mm Solder pins		
PCB	EB-596/228	

The 6C33C-B KIT

The Borbely Audio Kit includes:

6C33C-B with grid and cathode resistors (2)
Ceramic sockets for the 6C33C-B (2)
EB-696/224 output transformers (2)
1 pair of EB-396/225 driver boards (two-stage driver as shown in *Fig. 4*)
Optional: 1 pair of EB-596/228 power-supply boards (as shown in *Fig. 5*)

Specifications for the EB-696/224 output transformer (subject to change without notice):

Power rating: 30W
Primary imp.: 600Ω
Secondary imp.: 4Ω, 8Ω
Primary current: 0.4A
Secondary current: 3A
Frequency response: 20Hz: −1.5dB
50kHz: −2.7dB
Weight: approximately 3kg.

Mains transformer, connectors, switches, etc., are not included in the kit; however, Borbely Audio can deliver these on request. Please send for a quote.

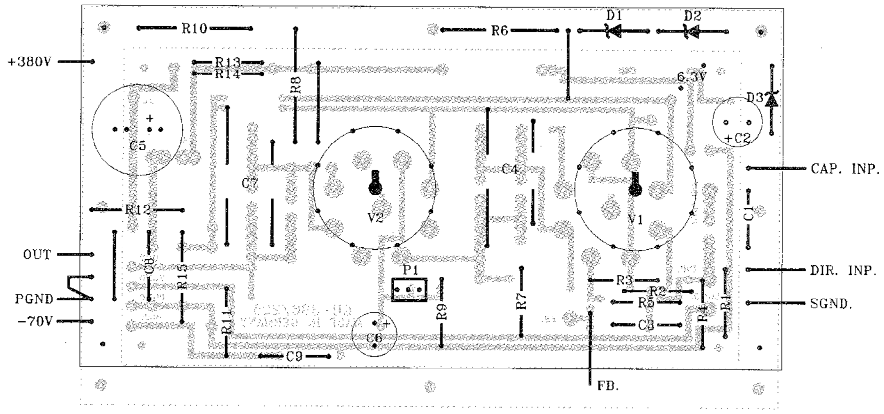

FIGURE 7: Stuffing guide for driver board.

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output transformer, it is easy to apply a small amount of feedback around the amp without instability problems. I urge you to experiment, both in terms of driver circuits and ways of reducing the inherent distortion in the SE output stage. Naturally, if you want to preserve the inherent distortion of the SE amplifier, you can remove the distortion-cancellation circuit and the feedback. *Tables 3* and *4* are the parts lists for the driver board and output stage.

Power Supply

You can conceive of the power supply for this amplifier in many different ways. Tube rectifiers for the output stage would probably cause too much voltage drop and are not recommended. Borbely Audio offers a power-supply board that provides two high-voltage rectifier sections, one for the output tube and one for the drivers. All diodes are fast/soft recovery types. The output tube is fed from a C-L-C filter, and the drivers from a C-R-C filter.

Since the 6C33C-B takes about two minutes to warm up, I have indicated a switch between the transformer and the supply, so that you can switch on the high voltage after two minutes. To the best of my knowledge, cathode stripping should not occur at the low voltage

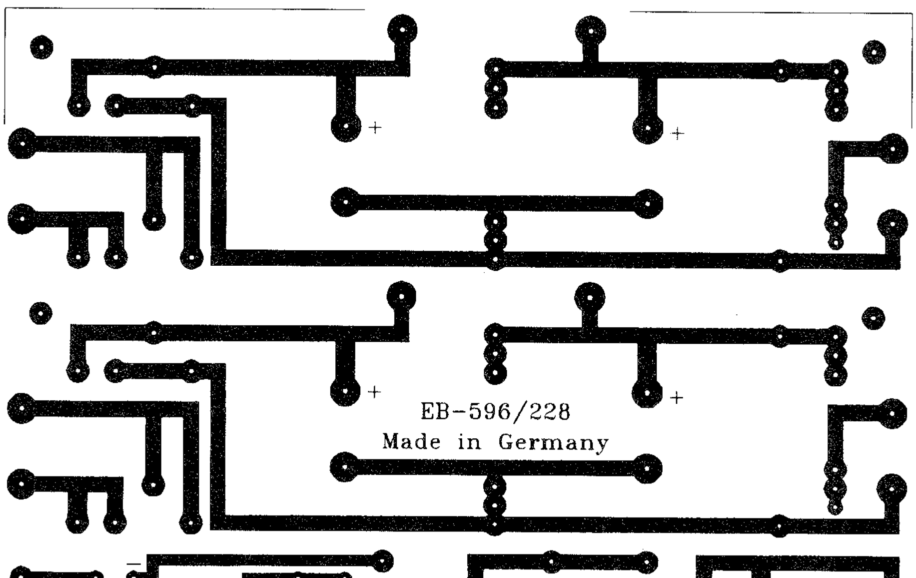

FIGURE 8: Power supply for tube amplifiers (1:1).

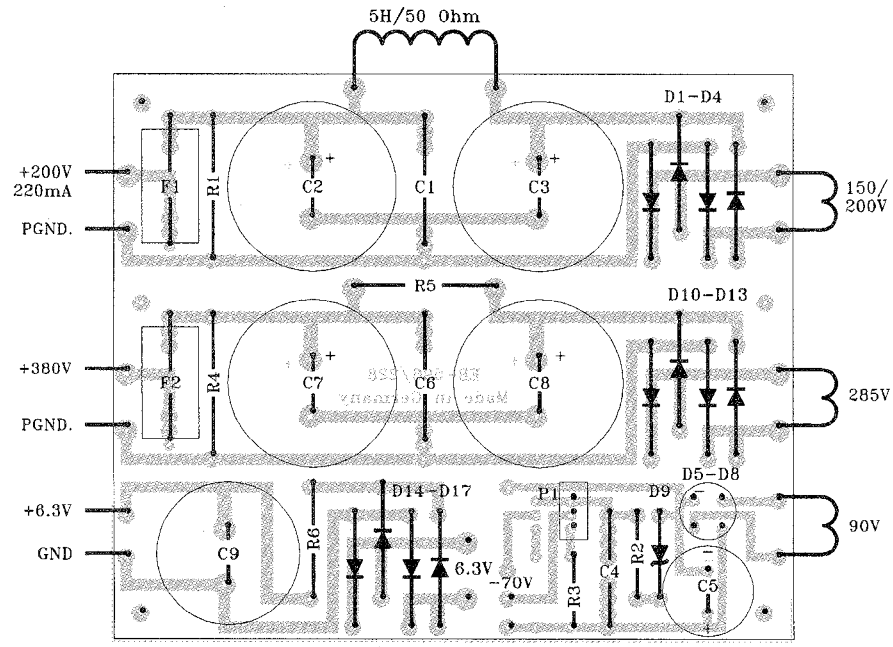

FIGURE 9: Stuffing guide for 6C33C-B power supply.

you are using here, but not knowing all the nitty-gritty of the 6C33C-B, it might be a good idea to exercise some caution. It is very important to have a well-filtered supply to avoid driver hum. Consequently, if you have a small choke in your jolly box, it is worth using it to replace the resistor in the driver power supply.

The driver tubes are heated with DC. A 3A bridge and a 10,000µF cap off the 6.3V will do it. Check the DC voltage on the tubes, and if it is more than 6.3V, connect a small resistor in series with the filter capacitor. The filaments are biased at approximately +100V on the driver board to avoid cathode-filament breakdown and to reduce hum. Alternatively, you can use one of the filament regulators offered by Borbely Audio.

Bias Compensation

The bias voltage, in case you choose to use fixed bias, should be present before you switch on the anode voltage. You can do this with a diode bridge and a capacitor. However, note that an increase in mains voltage causes a significant increase in the anode current if you keep the bias constant. To compensate for this, you need to increase the bias faster—percentage wise—than the mains voltage is increasing.

Ideally, an increase in mains voltage should not cause any increase in the anode current. Practically speaking, the increase should be kept to, say, less than 20mA over a mains voltage increase of 20V. Again using an idea from Johan Bernstrøm, you can do this with a zener diode in series with a resistor chain, as shown in *Fig. 5*. This circuit ensures that the anode current doesn't run away with an increase of the mains voltage. *Table 5* shows the power-supply parts list.

Monoblocks

I recommend you build the 6C33C-B SE amplifier as a monoblock, which ensures short cables between the amp and the speaker and lets you optimize the power supply and the internal wiring. The wiring of the amplifier is partially point-to-point, in that the 6C33C-B has a chassis-mount socket and the grid and cathode resistors must be wired directly to the socket. The rest of the amplifier, including the power supplies, can also be hand-wired, or, as with the Borbely Audio Kits, can be made on PCBs. (*Figures 6–9* show the driver and power-supply printed-circuit boards.)

Setup Procedure

The 6C33C-B SE amplifier requires very little setup. Obviously, you need to check all the voltages on the power supply and the driver board according to the schematics. Although the voltages used in this amplifier are relatively low, I recommend exercising utmost caution when testing the circuits. If you have no experience with tube circuits, I recommend that you ask an experienced friend or an electronics technician to test your amplifier.

To make the distortion-cancellation adjustment, you need a distortion analyzer. Adjust the output to 4V RMS/1kHz across the 8Ω load and measure the distortion. Adjust P1 slowly until you observe a dip in the distortion. Check the distortion at other levels, just to make sure the circuit is working properly. If you don't have a distortion analyzer, put a jumper in place of P1. No further adjustments are required. ❖

REFERENCES

1. The concepts of "distortion cancellation" and "bias compensation" are the intellectual property of Johan Bernstrøm, Sentec AB, Sweden.

SOURCE

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