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READING GLASS

In this issue, we are pleased to present yet another design by **Erno Borbely**. This one is a hybrid tube/MOSFET line amp that demonstrates operation at low-voltage values ("Low-Voltage Tube/MOSFET Line Amp," p. 1).

No doubt you've run across a variety of tube testers in your travels and

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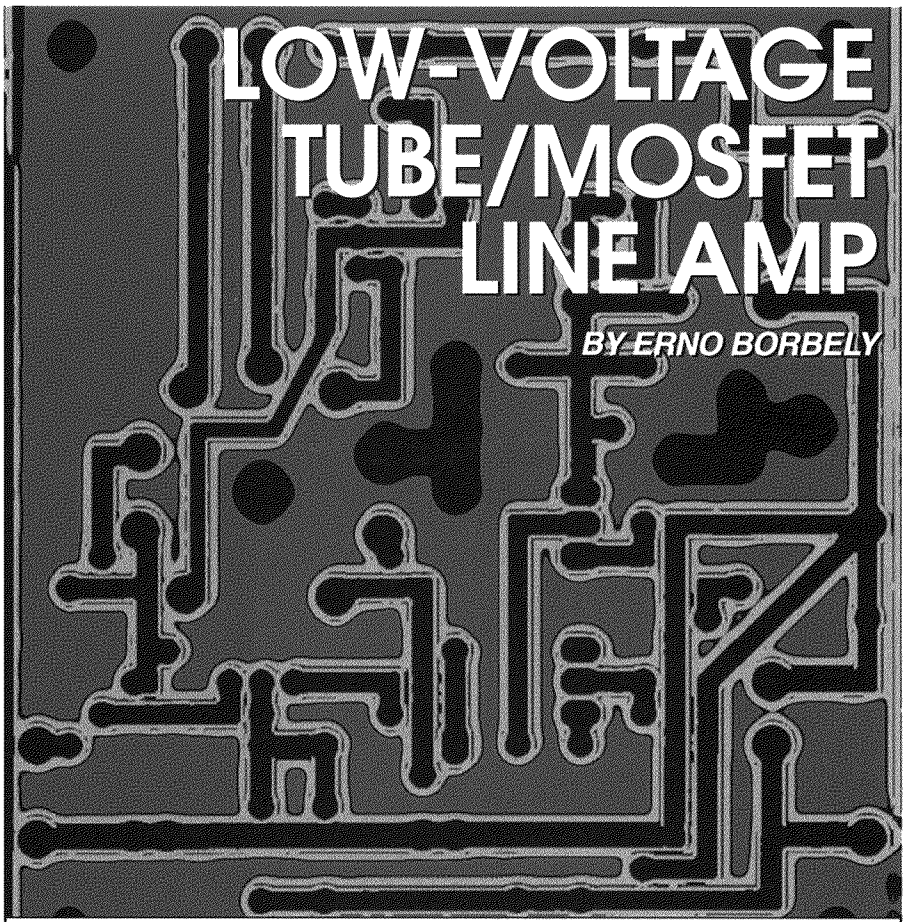
GLASS AUDIO



LOW-VOLTAGE TUBE/MOSFET LINE AMP

BY ERNO BORBELY

Most of today's tube circuits are using a relatively high voltage for the anode circuits. The lowest I have seen was the phono section of probably one of the most famous preamps of the tube era: it was using a pentode with about 25V anode voltage. Seeing this reminded me that you can also operate high-voltage tubes from lower voltages.

Low-Voltage Tubes

Of course, there are tubes that were specifically designed to operate from low voltages. Car-radio tubes are in this category. If you look at your tube catalogs from the late '50s and early '60s, you will find a number of tubes whose maximum anode voltage is specified at 30V.

One of these is the ECC86/6GM8. It is a double triode, with separate cathodes, intended for cascode RF operation. Specs are given at 6.3V, 12.6V, and 25V anode voltage. Typical specs at 6.3V anode voltage are:

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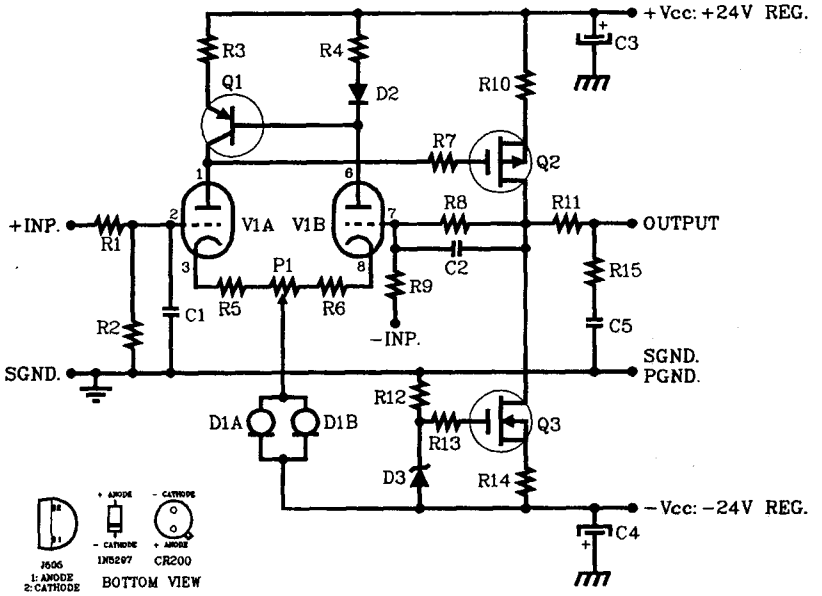

FIGURE 1: The input stage of the EB-797/203 is a differential amplifier with the ECC86.

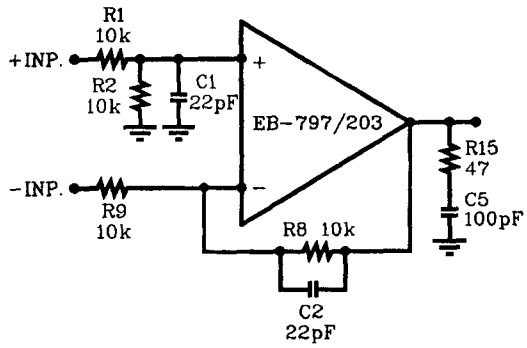

FIGURE 3: Balanced-to-single converter.

from page 1

S (sensitivity) = 2.6mA/V
μ = 14

These are indeed very low values, but S goes up to about 7.8mA/V at 25V anode voltage, which is reasonable. Obviously, if you want to use it for audio, you should do so at as high an anode voltage as possible. By the way, the maximum dissipation per system is 0.6W, so you can drive these tubes at a fairly high anode current.

Hybrid Operation

I have tried the ECC86 alone, both as a normal common-cathode amplifier and as a differential amplifier, with disappointing results. As expected, you can't really get much of a useful swing out of it compared to normal, high-voltage operation. However, because of the low anode voltage, it is easy to use the ECC86 in hybrid amplifiers with semiconductors.

MOSFETs, due to their tube-like characteristics, are particularly well suited to operate together with tubes. Other semiconductors, like constant-current diodes, help overcome some of the limitations of tubes and also help interface to other devices.

The EB-797/203 Hybrid Amplifier

The EB-797/203 is a DC-coupled hybrid tube/MOSFET amplifier. It uses a ±24V anode supply and 6.3V for heating. Its input stage is a differential amplifier with the ECC86 (*Fig. 1*), each half of the stage operating at approximately 2mA. A constant-current diode (D1) supplies the cathode current. D1 is made up of two CR200 2mA or two J508 2.4mA diodes in parallel. You can also use one J511 diode, which delivers 4.7mA.

The two anodes, which produce two out-of-phase signals, are converted to a single-ended signal, using a so-called current mirror, composed of Q1, D2, and resistors R3 and R4. Q2, a P-channel MOSFET of type 2SJ79, is used in common-source mode as a Class-A single-ended second stage. Its drain resistor has been replaced with a second constant-current source supplying 10mA. This is done to increase its gain and improve its linearity. This current source is made up of Q3, an N-channel MOSFET of type 2SK216, and its associated components.

The open-loop gain (OLG) of the amplifier is relatively high compared to tube amplifiers, but low compared to semiconductor amps.

Open-loop gain: 53dB
Open-loop (OL) frequency response without R15-C5: 90kHz
OL frequency response with C5 = 100pF: 55kHz
OL frequency response with C5 = 330pF: 35kHz
OL THD: 1kHz, 1V: 0.15%
3V: 0.35%
10V: 1.2%

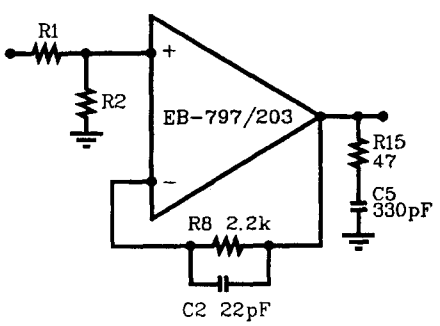

FIGURE 2: Unity-gain, noninverting buffer.

A Linear Amplifier

As the measurements show, the amplifier is very linear, but more importantly, the THD is practically all second harmonic. However, due to the relatively high OLG, you can't use it without feedback. You apply feedback through resistors R8 and R9, and you can set the customary 20dB line-amp gain with R8 = 10k and R9 = 1.1k. C2 applies phase compensation, adjusted for best square-wave response. *Table 1* shows the closed-loop gain.

Naturally, you can also use the amplifier with other gain settings. If you need less than 20dB gain for your CD player, then all you need do is increase R9. Making R9 = 10k will give you just 6dB gain. The amplifier is not unity-gain stable without the R15-C5 network at the output. R15-C5 rolls off the open-loop response of the amplifier, allowing it to work with low gain-setting, so if you want to use the amp with 6dB gain or less, you need to install R15-C5. C5 is 100pF for 6dB gain, and 330pF for unity

gain. *Figure 2* shows the amplifier as a unity-gain buffer.

The amplifier can also work as a balanced-to-single converter (*Fig. 3*). Resistors R1, R2, R8, and R9 are all 10k, and capacitor C2 is 22pF. Common-mode rejection is about 50dB without matching the two sides of the ECC86 and without trimming the resistors. Single-ended gain, with R9 grounded, is unity, while the gain in balanced-to-single configuration is 6dB. If you need a higher input impedance for interfacing to tube circuits, for example, you can increase the value of the resistors to about 100k.

Since the amplifier behaves like an operational amplifier, you can also use it with its negative input as an inverter. *Figure 4* shows the amplifier connected as a unity-gain inverter/mixer. More importantly, because the negative input is a so-called summing point, with very low impedance, you can also use the amp as a current-to-voltage (I/V) converter (*Fig. 5*). You can replace the 5534-based I/V converter in your CD-player with this amp, and enjoy an entirely new sound.

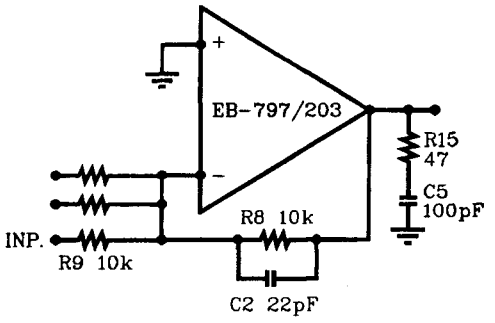

FIGURE 4: Unity-gain, inverting amplifier/mixer.

TABLE 1

CLOSED-LOOP PERFORMANCE

Closed-Loop Gain (CLG):	20dB
Closed-Loop (CL) frequency response:	–1dB at 700kHz
CL THD: 1kHz, 0.65V:	0.005%
2V:	0.009%
3V:	0.013%
5V:	0.021%
10V:	0.045%
15V:	0.2% (limiting)
Rise time: 0.5 µs @ +10V peak	
Equivalent input noise: approximately 1.2µV	
Output impedance: 50Ω	
Minimum load for 10V output: 10k	

Other Tubes?

It is a misconception that normal tubes can work only with high anode voltage. Insert a 6DJ8/ECC88 instead of the ECC86/6GM8 and observe its operation. It works very well indeed; in fact, the open-loop gain goes up by about 6dB! However, it works even better if you increase the anode voltage to, say, 30-40V, but you need to watch the power dissipation in the MOSFETs with higher voltages. Small heatsinks on the MOSFETs are advisable with increased supply voltage.

Setup Procedure

If possible, test each amplifier module separately before installing it in the box. This simplifies measurements, adjustments, and–if necessary–component changes. If you have access to an oscilloscope, connect it to the output of the amplifier and check to see whether radio frequency (RF) oscillations are present. If you have a complete audio instrumentation setup in your workshop, perform the usual gain, frequency-response, noise, total-harmonic-distortion (THD), and intermodulation measurements (IM). You should short inputs to ground under DC measurements or adjustments.

Connect a ±24V regulated anode/drain supply and 6.3V heater supply to the amplifier module. Connect a DC millivoltmeter to the output and adjust the output offset to zero with P1. Connect the DC voltmeter across R14 and measure the voltage drop. It should be a minimum of 1.6V, indicating a current of approximately 10mA in the second stage.

If the current is less than 10mA, decrease the value of R14, or shunt R14 with a resistor of larger value. If it is significantly larger than 10mA, then increase the value of R14. To double check, measure the voltage across R10 (200Ω); it should be 2V, +10%, –0%.

Remove the short circuit from the input and connect an audio oscillator to it. Adjust the level to 0.5V RMS at 1kHz. Connect an audio voltmeter or a distortion analyzer to the output and measure the output voltage. It should be 5V. Check the distortion, which should be less than 0.05%. ❖

TABLE 2

PARTS LIST

(All resistors are 0.5W/1% metal film, ROE MK-2, or the equivalent.)

Resistors

R1, R5–7, R13	100
R2	100k
R3, R4	499
R8, R12	10k
R9	1.1k
R10	200
R11	47.5
R14	165
R15	see text

Trimpot

P1	100 multiturn cermet

Capacitors

C1	100pF/630V PP
C2	22pF/630V PP, PS
C3, C4	220µF/63V ROE/Frolyt EKR
C5	see text

Tube

V1	ECC86/6GM8

Semiconductors

Q1	2SA872
Q2	2SJ79
Q3	2SK216
D1	2 × J508 (in parallel)
D2	1N4148
D3	LM336Z-2.5

Miscellaneous

12 × 1mm solder pins
PCB: EB-797/203 (70 × 80mm)

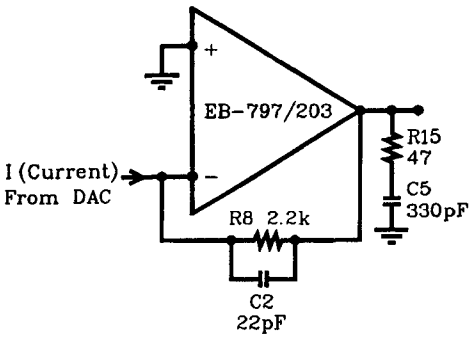

FIGURE 5: I/V converter.

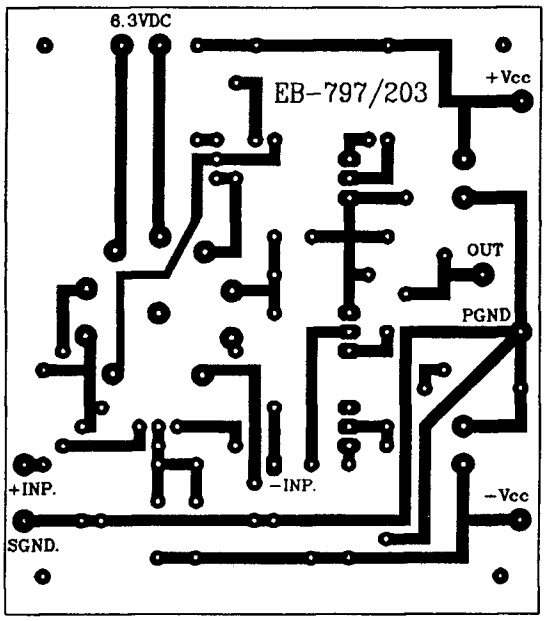

FIGURE 6: Hybrid line amplifier copper side (100%).

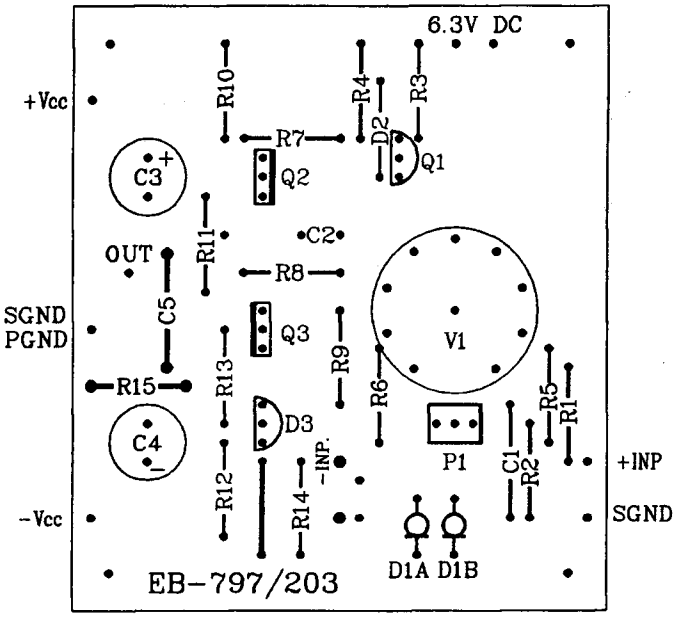

FIGURE 7: Component side for low-voltage tube/MOSFET line amp (100%).