The Open-Source Directly-Heated Triode Electrostatic Headphone Amplifier (OSDEHA)

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THIS DOCUMENT IS UNDER CONSTRUCTION!
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Warning: This DIY project involves high voltage. Individuals utilizing the information provided must possess expert knowledge, adhere to stringent safety precautions, and accept all risks associated with electrical work. The authors and contributors of this project expressly disclaim any liability for injuries or damages arising from the use or misuse of this information.

1. OVERVIEW

This document describes an audio amplifier for electrostatic headphones. The design of the amplifier is targeted at DIY builders and is published as open hardware (see Sec. 4).

Electrostatic headphones operate on audio signals characterized by high voltage and low current. This is the domain of vacuum tubes, making them most suitable as drivers for e-stats. While there exist a number of tube amplifiers for e-stat headphones, many of these designs do not utilize directly-heated triodes (DHTs), which exhibit outstanding linearity and sound quality.

The OSDEHA uses DHT tubes for its output stage and implements the following design goals:

- The audio output is taken directly from the anodes of the DHT output tubes. There are no transformer or capacitors to transfer the power to the headphones.
- The amplifier input takes balanced input at signal levels of modern audio sources (mostly DACs these days).
- The design prioritizes the quality of audio reproduction and electronic design rather than on low cost.
- The amplifier should be reasonably compact, and all units and boards should fit in one single chassis.

There is a public discussion thread of the OSDEHA at diyAudio.[1]

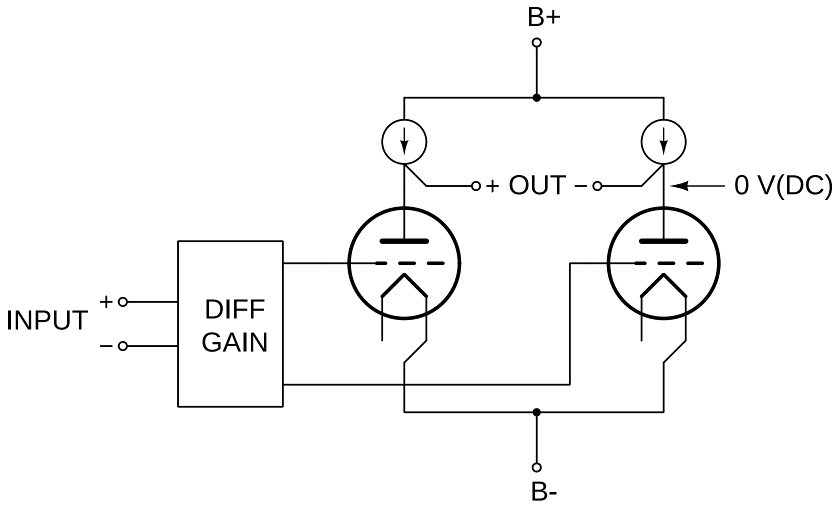

Figure 1: Conceptual layout of the OSDEHA: differential input, gain stage stage, and push-pull DHT output stage.

2. AMPLIFIER CIRCUIT

2.1. Driving electrostatic headphones

Electrostatic headphones utilize three electrodes: two fixed outer electrodes (stators) and a movable central electrode (diaphragm). The diaphragm is biased at a high voltage relative to the stators. The audio signal is applied to the stators in opposite polarities, creating an electric field that controls the movement of the charged diaphragm. For accurate sound reproduction, the electrostatic forces acting on the diaphragm must be proportional to the applied audio signal. To avoid distortion of the audio output from the headphone, the charge on the diaphragm therefore needs to be maintained constant.

The electrical impedance of electrostatic headphones is primarily determined by the capacitance of the two stators, which is typically around 100 pF.[2]

The voltage swing to drive the stators depends on the headphone sensitivity and the desired sound pressure level. An experiment using various genres of well-recorded music indicated that an undistorted 1.3 kV peak-to-peak swing of the bipolar output is desirable (i.e., 650 V peak-to-peak at each stator).[3] The corresponding current swing measured in this experiment was approximately 4 mA, but driving the 100 pF load to full output at 20 kHz and higher necessitates larger peak currents, around 20 mA.[4]

2.2. Output Stage

Fig. 1 shows the conceptual layout of the OSDEHA. The output stage uses two DHTs in a push-pull arrangement to provide the symmetric, bipolar output needed to drive electrostatic headphones. For efficient transfer of the audio power to the headphones, the AC impedance of the anode loads must be larger than that of the headphones (several MΩ). This cannot be implemented with passive anode-load resistors, so active constant-current sources (CCSs) are used in this position. The CCS loads also improve the linearity and voltage gain of the amplifier, and suppress ripple and noise from the B+ rails.

The choice of the output tube type is determined by the drive requirements for the headphone, as described in Sec. 2.1. Since the two tubes are in series with the headphone, each tube

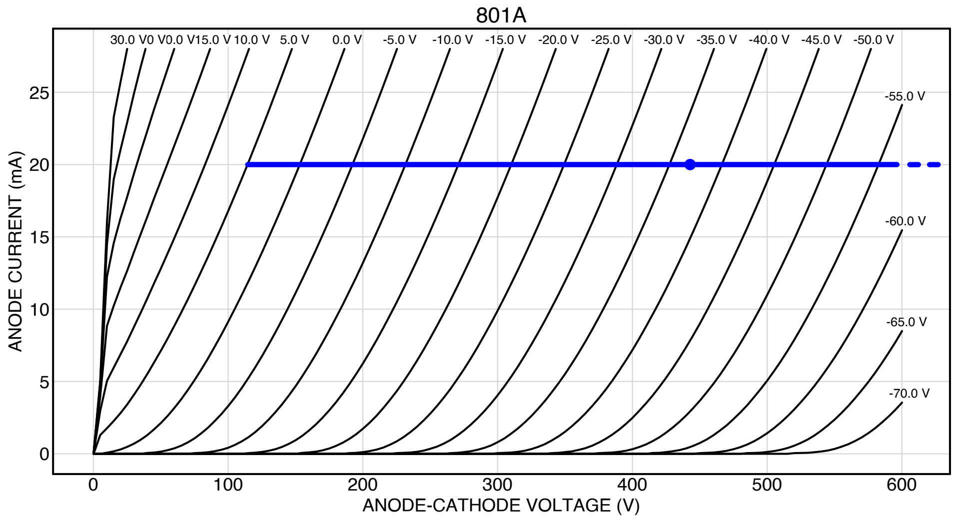

Figure 2: Characteristic curves measured from an 801A DHT, with 20 mA CCS load line and a 440 V bias and a ±325 V anode swing (blue).

contributes half of the total voltage swing. Each tube needs to swing ±325 V at a 20 mA bias. Additionally, to emphasize the "DHT sound," the DHT output stage should contribute as much voltage gain as possible to the overall gain of the amplifier.

Several DHT tube types were considered for the OSDEHA.[5,6] In particular:

- The 841/VT-51 tube has a gain of 30× and can be biased up to 425 V. However, at the operating point required for the OSDEHA, the 841 tends to operate at a positive grid voltage, which leads to grid current draw. Moreover, these tubes are relatively scarce.
- The 20B tube is a modern design with a gain of 20×, the 20B can be biased up to about 500 V. However, these tubes are quite large (approximately the size of a beer bottle) and are manufactured in small quantities by a single producer (Emissionlabs), making their long-term availability uncertain.
- The family of the 801/801A/VT-62 and 10Y/VT-25 types[7] provide a gain of 8×. The 801 can be biased up to 500 V, while the 10Y should not be biased above 450 V. These tubes are available as new-old-stock and from new production.

From a technical standpoint, the high gain of the 20B would would make this tube an interesting option. However, due to concerns about the long-term availability of the 20B, the 801/10Y family of tubes is considered a more practical choice for the OSDEHA design.

Fig. 2 shows the characteristic curves measured from the 801A tube (the 10Y/VT-25 are equivalent) with the load line of a 20 mA CCS. The anode DC bias is set at 440 V, corresponding to a grid bias of approximately –37 V. This bias point facilitates an anode voltage swing of ±325 V within the linear operating range of the tube. Additionally, the grid voltage does not exceed +5 V, where the grid current has been measured to stay well below 1 mA.

Fig. 3 shows the simplified circuit of the CCSs used to load the anodes of the DHT output tubes. This AC-coupled CCS circuit is sometimes (incorrectly) called a "gyrator"[8] and works as a CCS in the audio/AC domain only, while it outputs a fixed voltage in the DC domain.[9] In both cases, the FET Q1 controls the output of the circuit to the anode, while the depletion-mode FET Q2 drops most of the voltage from B+ and decouples Q1 from any noise or ripple that may be present in

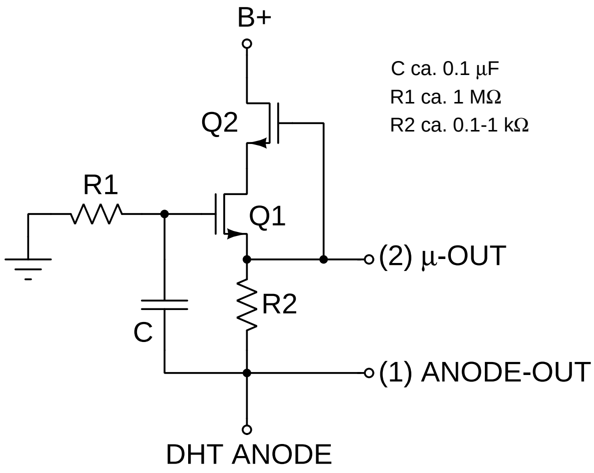

Figure 3: Gyrator CCS circuit (simplified).

the B+ supply.

In the audio/AC domain, the gate of Q1 is tied to the anode through capacitor C. Q1 mirrors any AC variation of the anode voltage from the gate to its source pin. This maintains a constant voltage between the Q1 source and the DHT anode, and thereby keeps the current through R2 constant. If the headphone stator is driven directly by the DHT anode (output 1 in Fig. 3), this current is shared between the DHT and the stator. Therefore, the current flowing through the DHT will exhibit a slight variation in response to the AC current draw by the stator. This variation is typically less than 4 mA,[3] which is considerably less than the DC bias current. The general concept for the operating point illustrated in Fig. 2 therefore remains valid. However, instead of taking the audio output from the DHT anode, the stator can also be connected to the μ-output of the gyrator (output 2). In this μ-follower configuration,[10,11] the stator does not draw any current from R2, which restores the constant-current operation of the DHT tube with a perfectly flat load line as shown in Fig. 2.

In the DC domain, the gate pin of the FET Q1 is grounded via R1, and the source pin is therefore fixed at $-V_{\mathrm{GS},0}$. This biases the anode at a small negative DC voltage determined by $V_{\mathrm{GS},0}$ and the DC drop across R2. This maintains a stable DC voltage at the amplifier outputs despite any thermal drift or aging of the DHT tubes.

2.3. Input Stage

The task of the input stage is to amplify the balanced input signal (2 $\times$ 3.5 V peak-to-peak) to drive the DHT grids (2 $\times$ 86 V peak-to-peak). To this end, a voltage gain of $86/3.5 = 25\times$ is needed.

Following the lines of the output stage, the differential input stage is designed as long-tailed pair (LTP)[12] using tubes with triode characteristics. The linearity and the voltage gain of the LTP is optimized with a very high AC impedance of the “tail”, which is implemented as a CCS (Fig. 4).

The E180F or 6E5P tubes connected as triodes provide suitable gain and offer very linear amplification.[13–15] However, the E180F tends to be microphonic,[16] and its linearity was found to be slightly inferior to that of the 6E5P,[17] making the 6E5P the preferred choice for the LTP input stage.

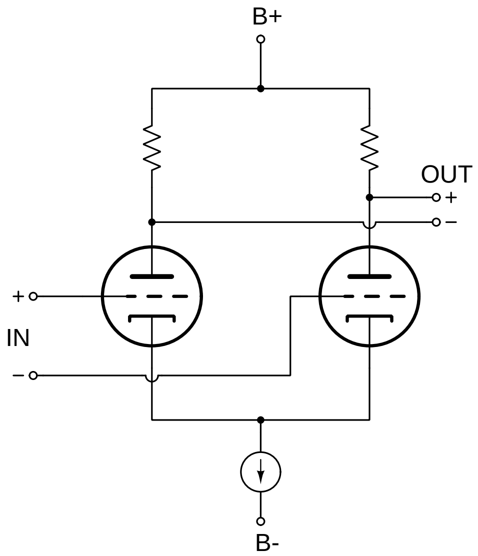

Figure 4: Input stage (simplified).

———— COUPLING AND BUFFERING TO OUTPUT STAGE DHT GRIDS: The grids of the output tubes will be biased below the B- / -HV rails, so it would be rather complicated to DC couple the LTP input/driver stage to the output stage. Capacitor coupling works very well [https://linearaudio.net/cyril-batemans-capacitor-sound-articles], especially if there is no substantial current flowing through the capacitor. Driving the output stage into A2 therefore needs a current buffer. A MOSFET source follower should do the trick. ————

3. POWER SUPPLIES

3.1. High voltage supplies (B+, B-, B2-)

3.2. Bias

3.3. DHT filament supply

3.4. Heater supply for input stage

4. LICENSE INFORMATION

other products you make using this source.

REFERENCES

[1] https://www.diyaudio.com/community/threads/open-source-dht-estat-headphone-amp-osdeha.407679.

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[17] https://www.diyaudio.com/community/threads/open-source-dht-estat-headphone-amp-osdeha.407679/post-7592439.