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A High-Quality, High-Power Headphone Amplifier

Design is based on superior op-amps used in audio applications

Headphones have an important advantage over loudspeakers. They completely remove the room acoustics, which makes them an ideal tool for speaker designers. A high-quality pair of headphones reproducing a well-known recording can serve as a reference when evaluating a newly designed loudspeaker. Of course, a high-quality amplifier must drive high-quality headphones. This article describes the design and construction of a high-quality, high-power headphone amplifier (see **Photo 1**).

Photo 1: The completed headphone amplifier has a clean and simple design.

DESIGN OBJECTIVES

When built, I wanted the amplifier to deliver at least 1 W_{RMS} at 32 Ω. This meant the amplifier must have 5.7-V_{RMS} output voltage, which is more than enough to drive any headphone to its maximum sound level. I wanted all the amplifier's components, including the power supply (with the exception of the transformer), to be placed on a single PCB for ease of construction. The amplifier needed a volume control so it could be directly driven from the analog output of a CD/DVD player, a phono preamplifier, or any other analog source.

The amplifier also needed to be used as a high-quality line preamplifier. The amplifier design is based on high-quality op-amps used in audio applications.

THE AMPLIFIER'S DESIGN

Figure 1 shows a simplified block diagram of the headphone amplifier. The design consists of three main blocks: the amplifier circuit, the power supply, and the protection circuit. **Figure 2** shows the amplifier's complete electronic schematic. The schematic only shows one channel, however, the other channel is identical.

The amplifier circuit includes the volume control, the gain amplifier, and the output buffers connected in parallel. The circuit's first section is the RF filter for electromagnetic interference (EMI) protection, consisting of R9 and C3. These components create a low-pass filter at about 340 kHz. The previous stage's output impedance can lower the low-pass filter's corner frequency. So, if this impedance is greater than 500 Ω, the capacitor C3 should be decreased accordingly to prevent excessive high-frequency loss.

Next, there are three pins to connect the volume control potentiometer, which is on the amplifier's front panel. The volume control's position at the input protects the amplifier's next stages from any possible overload. I used an Alps Electric 100-kΩ stereo potentiometer for the volume control.

I used the capacitor C4 for the DC protection of the following circuitry. This is the only capacitor used in the amplifier's audio signal path. I needed resistors R14 and R38 to ensure a DC path for the circuit's proper operation.

The first part of the IC1 consists of a noninverting gain stage for the amplifier and it also drives the next circuit. For this position, I used a Texas Instruments OPA2134 op-amp, which is a low-noise, ultra-low distortion amplifier especially designed for audio applications. As indicated in the schematic, I set the gain to about 7.5 dB. This enabled the amplifier to fully drive most headphones.

But, be careful! If the amplifier's

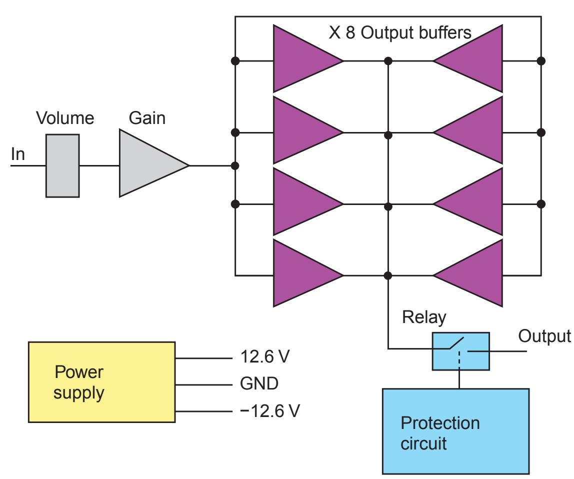

Figure 1: The headphone amplifier includes an amplifier circuit, a power supply, and the protection circuit.

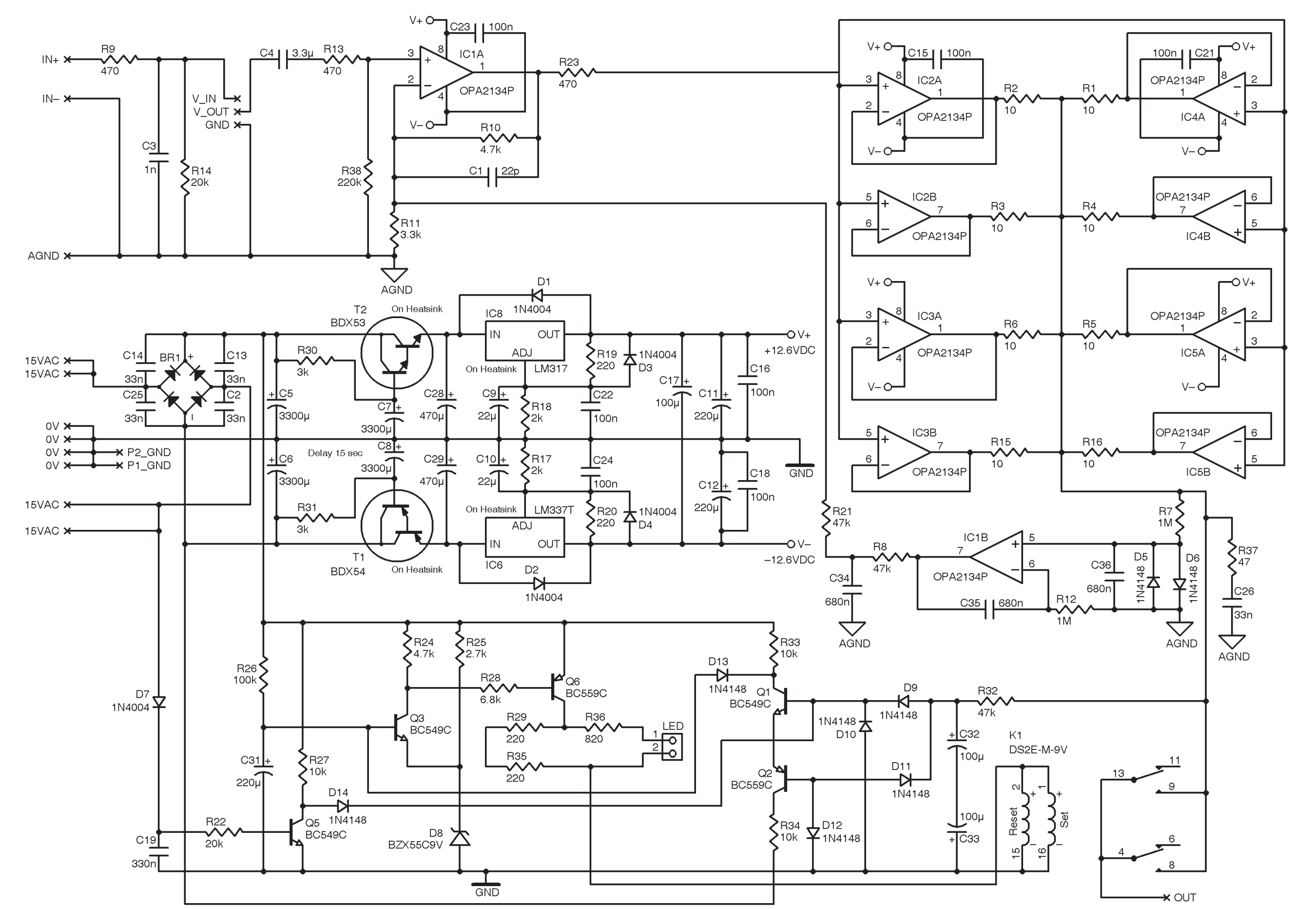

Figure 2: The headphone amplifier's electronics are built around a Texas Instruments OPA2134 op-amp.

volume is left at its maximum value when the amplifier's input is directly connected to a CD or DVD player's output (which means a full signal of 2 V_{RMS}), the amplifier's output voltage could blow out your headphones and perhaps your eardrums. It is safest to always power up the amplifier with the volume set to its minimum position.

If your headphones are sensitive, you may want to reduce the gain. This can be done by increasing the value of R11. The output circuit consists of eight op-amps working as voltage followers with their outputs connected in parallel by 10-Ω resistors. I chose the OPA2134 op-amp for this position for the same reasons I previously mentioned and also because it can drive 600-Ω loads at a full output voltage. Each OPA2134 op-amp's output current capability is 35 mA, according to the datasheet. So, the amplifier's total output current capability is 280 mA peak (i.e., 8 × 35 mA). With a 32-Ω output load, the amplifier's total output power capability is 1.25 W! The output voltage required for this power is 6.34 V_{RMS} or 9-V peak, which is within this circuit's capabilities.

The components R37 and C26 at the output help stabilize the amplifier's high-frequency behavior when driving long cables or difficult loads. The circuit around IC1B is a noninverting DC servo integrator, which keeps the amplifier's output at 0 V and eliminates any DC offsets of the circuit. Using the servo circuit also eliminates the need for a capacitor in the amplifier's feedback loop.

I used an additional R-C low-pass filter consisting of R8 and C34 at the servo op-amp's output to completely attenuate any noise that might be driven to the amplifier's more sensitive first stage.

THE POWER SUPPLY

A 15-VA power transformer provides the required 2 × 15 VAC for the amplifier's power supply. A 2-A/100-V bridge rectifies the AC voltage to DC voltage and charges the two 3,300-µF capacitors. The capacitors C2, C13, C14, and C25 in parallel with the rectifier diodes reduce their noise.

The next stages with components around transistors T1 and T2 are classical capacitance multiplier stages. I used large-value capacitors (C7 and C8), which significantly attenuated the ripple voltage before it came to the LM317 and LM337 regulators. I adjusted the output voltage for each side to 12.6 and –12.6 V, accordingly.

The output bypass capacitors C11, C12, C16, C17, and C18 further improve the regulators' stability. I used diodes D1, D2, D3, and D4 to prevent the capacitors from discharging through low current points into the regulators. This protects the regulators from any possible damage.

The transistors (T1 and T2) and the regulators (IC6 and IC8) required some heatsinking to avoid high temperatures. I used isolators to screw them to an aluminum square rod (see **Photo 2**). I then screwed the aluminum rod to the amplifier's chassis. This was more than enough to keep them cool even when driving the maximum power.

PROTECTION CIRCUIT

The protection circuit is based on a 1999 *Electronics World* article by Douglas Self, which supports several basic functions. During the amplifier's power-on, it connects the output with a delay to avoid any transient noise. It quickly disconnects the output during the amplifier's power off or if a power loss happens. It continually senses the amplifier's output for DC voltages and quickly disconnects the output if there is any DC fault. This will protect the headphones if something goes wrong with the amplifier.

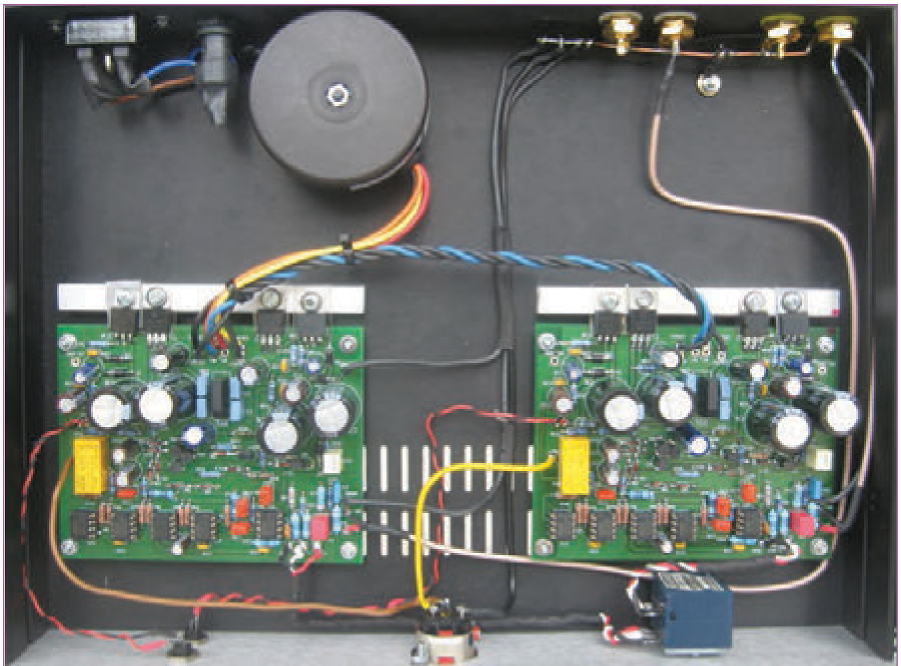

Photo 2: The headphone amplifier has a simple internal construction.

CIRCUIT OPERATION

When power is applied to the circuit, the components D7, C19, R22, and Q5 detect the presence of the 50-Hz line voltage and the transistor Q5 is set to the On status so the diode D14 is shorted to the ground. This prevents the circuit's activation around Q1 and Q2. The relay K1 is turned on with the RC constant's delay of R26 and C31.

The Zener diode D8 generates a 9-V constant voltage, which is used in conjunction with the capacitor C31's voltage for the output relay's activation. The capacitor C31's voltage is increased slowly by the R26-C31 constant. When it reaches about 9.5 V, the transistor Q3 is activated, which turns on the transistor Q6, activating the relay K1.

Any DC output offset at the output is sensed by the circuit around transistor Q1 and Q2 with the help of the diodes D9, D10, D11, and D12. The components R32, C32, and C33 create a low-pass filter at a very low frequency so the protection circuit cannot be activated by the output signal's strong bass frequencies. The transistor Q1 detects the positive DC voltage and the transistor Q2 detects the negative voltages. When the voltage

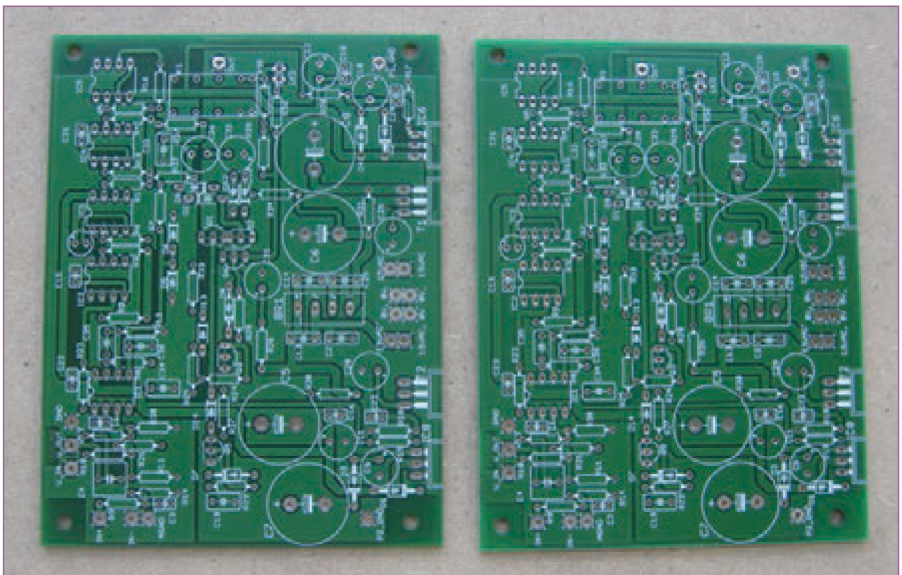

Photo 3: The stereo amplifier's construction requires two PCBs.

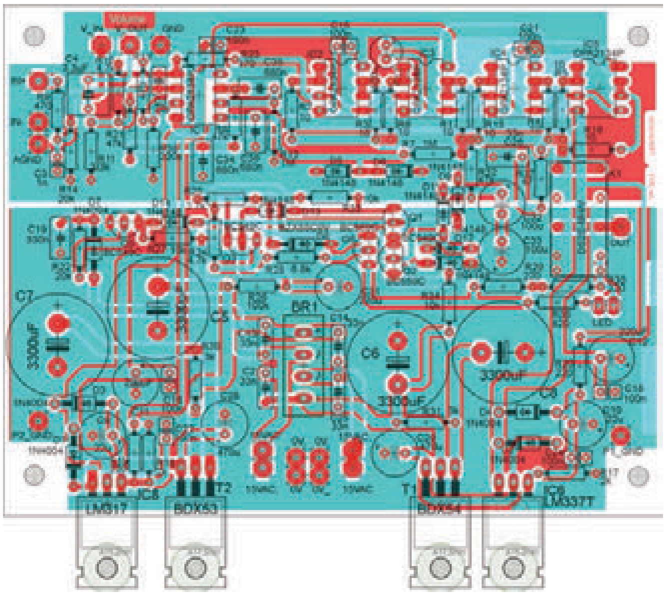

Figure 3: The amplifier's PCB assembly shows that the amplifier's signal ground and power supply ground are not connected to it to avoid ground loops problems.

is greater than about 2 or −2 V, the transistors Q1 or Q2 are activated and the relay K1 is deactivated quickly disconnecting the output. The LED is in series with the output relay. When the LED is illuminated, it indicates that no fault is detected by the protection circuit and the output is normally connected.

AMPLIFIER CONSTRUCTION

As previously mentioned, one of my design objectives is to have all the amplifier's components on a single PCB, simplifying its construction. I used a demo version of CadSoft's Eagle PCB software for the design. The program limited the PCB's maximum dimensions. The outcome was a 90-mm × 115-mm double-sided PCB with ground planes on the top and bottom layers. Each PCB has the components for only one channel, so I needed two PCBs for a complete amplifier.

Photo 3 shows the PCBs I used. These are high-quality PCBs with board material FR4 of 1.6-mm thickness and 35-μm copper. They also have plated through holes, solder resistance on both sides, and a silkscreen on the top side.

Figure 3 shows the PCB's complete guide assembly. The parts list shows what is required to build one channel. To construct a complete amplifier, double the parts list.

To avoid ground loop problems, the amplifier's signal and power supply ground are not connected on the PCB. They should be connected together at a common point near the signal input ground.

I used a metal enclosure with a 10-mm aluminum front panel to house all the amplifier's components. The enclosure had the following dimensions: 340 mm (width) × 5 mm (height) × 240 mm (depth). The amplifier's front panel has two LEDs on the left side, one for the left channel and the other for the right channel to indicate the amplifier's normal operation.

In the panel's center is a 0.25″ metal jack for the amplifier's headphone output. I used a Neutrik NJ3FP6C socket,

Headphone Amplifier Parts List

(for one channel)

All resistors are 0.25 W, 1%, except as noted

Part = Value

Capacitors
- C1 = 22p
- C3 = 1n, MKT
- C4 = 3.3 µF, MKT
- C5, C6, C7, C8 = 3,300 µF, 25 V
- C9, C10, C17 = 22 µ, 63 V
- C11, C12 = 100 µF, 35 V
- C31 = 220 µF, 25V
- C2, C13, C14, C25, C26 = 33 n
- C15, C16, C18, C21, C22, C23, C24 = 100 n
- C19 = 330n
- C28, C29 = 470 µ, 25 V
- C32, C33 = 100 µ, 16 V
- C34, C35, C36 = 680 n

Miscellaneous
- K1, Relay = DS2E-M-9V
- LED
- Transformer = 2 × 15 V/15 VA

Resistors
- R1, R2, R3, R4, R5, R6, R15, R16 = 10 Ω
- R7, R12 = 1 M
- R8, R21, R32 = 47 kΩ
- R9, R13, R23 = 470, 0.1%
- R10 = 4.7 kΩ, 0.1%
- R11 = 3.3 kΩ, 0.1%
- R14, R22 = 20 kΩ
- R17, R18 = 2 kΩ
- R19, R20, R29, R35 = 220 Ω
- R24 = 4.7 kΩ
- R25 = 2.7 kΩ
- R26 = 100 kΩ
- R28 = 6.8 kΩ
- R30, R31 = 2.7 kΩ
- R27, R33, R34 = 10 kΩ
- R36 = 820 Ω
- R37 = 47 Ω
- R38 = 220 kΩ

Semiconductors
- BR1, Bridge rectifier 2KBP = 2 A/100 V
- D1, D2, D3, D4, D7 = 1N4004
- D5, D6, D9, D10, D11, D12, D13, D14 = 1N4148
- D8 = BZX55C9V
- IC1, IC2, IC3, IC4, IC5 = OPA 2134
- IC6 = LM337T
- IC8 = LM317T
- Q1, Q3, Q5 = BC549C
- Q2, Q6 = BC559C
- T1 = BDX54
- T2 = BDX53

which is a high-quality socket with silver contact plating and a 10-A current rating. It has a locking capability that requires users to press a red button to release the headphone plug. The volume control sits on the front panel's right side. I used an Alps 100-kΩ stereo potentiometer. The aluminum knob is chromium plated for a nice appearance.

I used Front Panel Express's Front Panel Designer to create the text on the front plate. I used my ink-jet printer to print the front panel information on a transparent, self-adhesive sheet.

I mounted the power transformer as far as possible from the amplifier's electronics parts to avoid any interference. I mounted the two PCBs on the front side of the chassis, near the volume potentiometer and the output connector. The star point ground is close to the amplifer's input sockets. Here, the analog (AGND), the power ground (P1_GND or P2_GND) and the output connector's ground are connected together to the INPUT ground. I used two shielded cables to connect the input sockets and the PCBs. I used twisted cables to connect the volume control potentiometer.

Photo 4 shows the amplifier's back panel. On one side of the panel is an International Electrotechnical Commission (IEC) socket for the 230-V input and the fuse holder. The other side contains four gold-plated RCA phono sockets for the signal inputs and outputs. There is enough distance between them to avoid any interference from the line voltage to the signal voltages. The phono sockets are insulated from the chassis.

For all the amplifier's op-amps, I used high-quality IC sockets with gold-plated pins. This facilitates the testing of the amplifier and the repair in case of any problems.

You should test all the power supply voltages before inserting any op-amp into its socket. The protection circuit should also be tested to check its correct operation when a DC fault appears at the output. This is performed by removing all the output op-amps from their sockets (IC2, IC3, IC4, and IC5) and connecting an external power

Photo 4: The amplifier's back panel shows the in and out connections.

Load	8 Ω	32 Ω	100 Ω	300 Ω
Gain	6.52 dB	7.45 dB	7.6 dB	7.7 dB
Maximum output voltage	1.8 V_{RMS}	6.4 V_{RMS}	7.8 V_{RMS}	8.1 V_{RMS}
Frequency Response	1 Hz to 250 kHz	1 Hz to 250 kHz	1 Hz to 250 kHz	1 Hz to 250 kHz
Maximum output power	0.4 W_{RMS}	1.28 W_{RMS}	0.6 W_{RMS}	0.22 W_{RMS}

Table 1: The amplifier's measurement results were documented as it was consecutively connected to four different resistive loads.

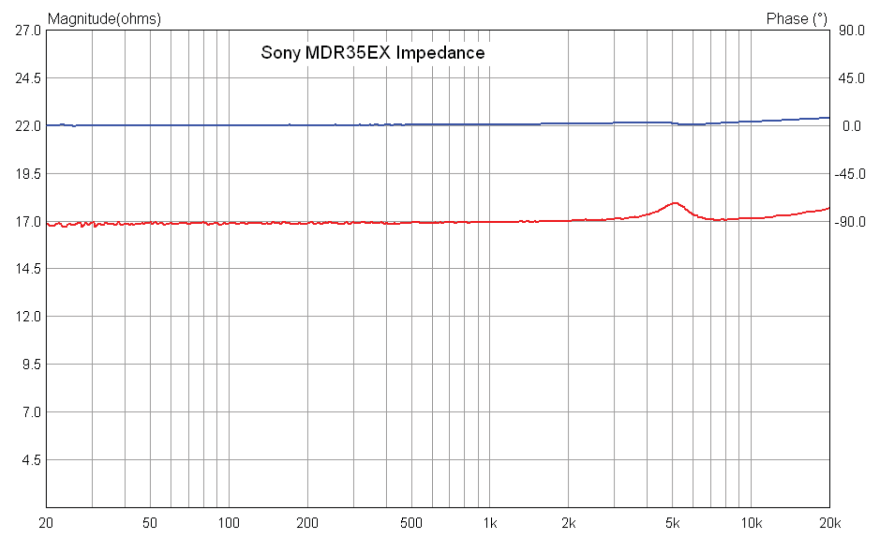

Figure 4: The Sony MDR35EX impedance is almost flat at 17 Ω.

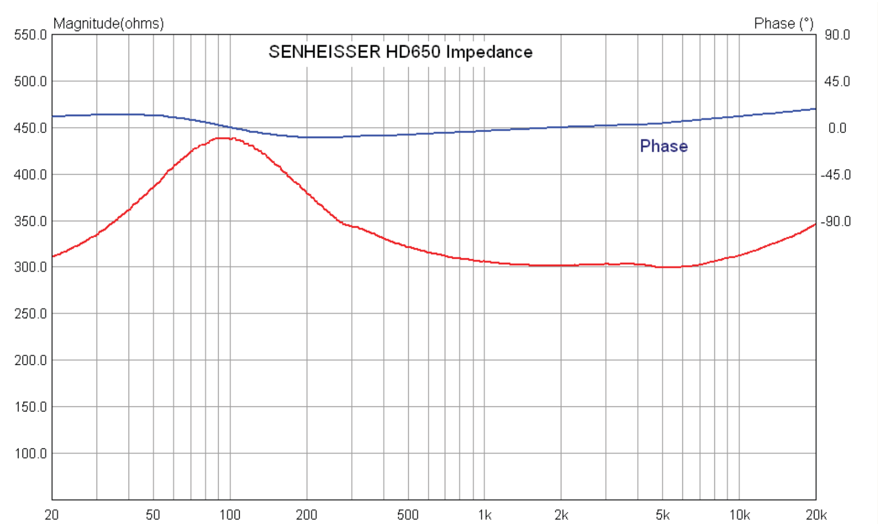

Figure 5: The Senheisser HD650 impedance is flat, close to 300 Ω.

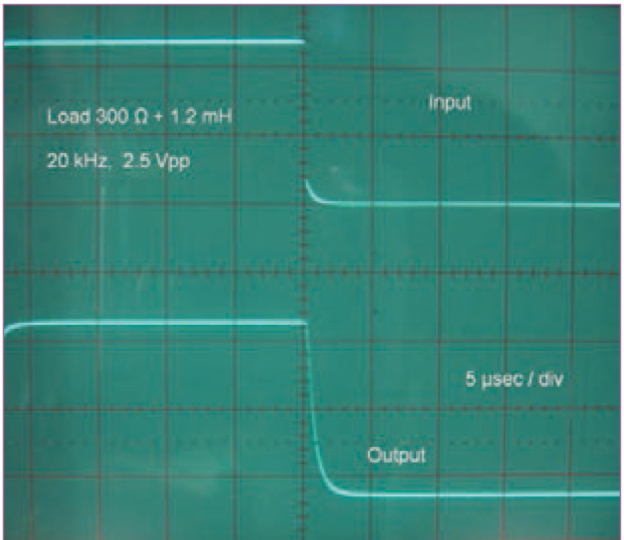

Photo 5: The amplifier response at 20 kHz shows a 2.5 V_{PP} with a 300-Ω load + 1.2 mH (falling).

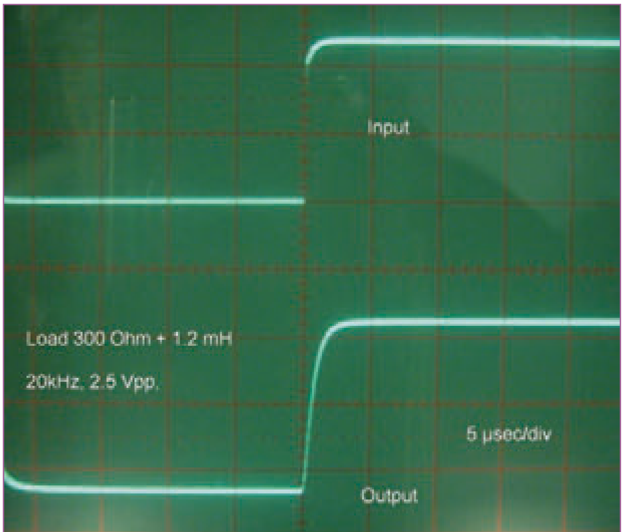

Photo 6: The amplifier response at 20 kHz also shows a 2.5 V_{PP} with 300-Ω load + 1.2 mH (rising).

supply or battery to the amplifier's output. To test it, provide a DC voltage of about 2.5 V first and then −2.5 V directly to the amplifier's output. This should activate the protection circuit relay by disconnecting the output.

AMPLIFIER PERFORMANCE CHECK

After constructing the amplifier, I performed several measurements to check its performance. The headphone amplifier's input was connected to my function generator and the amplifier's output was consecutively connected to four different resistive loads: 8 Ω, 32 Ω, 100 Ω, and 300 Ω. While 8 Ω is not a typical load for a headphone amplifier, I just used it to check the amplifier's capabilities.

For each of the loads, I measured each channel's gain, frequency response, and maximum output voltage just before clipping. I used an oscilloscope to monitor the output voltage (see **Table 1**).

The input impedance is about 15 kΩ. This impedance is easily driven by any CD or DVD player's output. It can be increased, if necessary, by increasing the R14's value. The amplifier's output impedance was measured below 2 Ω. This is a low-output impedance that could easily drive any low-impedance headphones.

To compare measurements, I also wanted to test the amplifier as it was driving an actual headphone load. But I was unable to increase the driving output voltage high enough without damaging the headphones, so I tested it with a simulated load. For this reason, I measured the impedance of two headsets I had available: the Sony MDR-35EX and the Sennheiser HD-650.

Figure 4 shows the Sony MDR-35EX's impedance. It is almost flat at 17 Ω with almost zero phase. Only a very small peak is shown at 5 kHz. So there is really nothing to simulate here.

Next, I measured the impedance of the Sennheiser HD-650 (see **Figure 5**). The test shows a resonance at about 100 Hz with a maximum 440-Ω impedance value. The impedance is flat, close to 300 Ω from about 1 kHz up to 7 kHz, and then it increases to 345 Ω at 20 kHz. The impedance in the range above 1 kHz could be simulated with a 300-Ω resistor in series with a 1.3-mH inductance. I had a 1.2-mH inductor available so I used this for the simulated load.

Photo 5 shows the amplifier's falling response when driving this load with a 20-kHz square wave at a 2.5-V_{PP} voltage level. **Photo 6** shows the amplifier's rising response. This is an excellent response.

EXPECTATIONS MET

This high-quality, high-power amplifier was very easy to construct. It has an excellent transparency, which I consider absolutely necessary to extract the best sound from whatever recording you might hear. Also, it is so quiet that it is difficult to determine whether the amplifier is powered on or off. Finally, it has enough power to drive almost any headphone. *aX*

RESOURCES

Front Panel Express, LLC, "Front Panel Designer 4.1.4," www.frontpanelexpress.com/download/front-panel-designer/index.html.

D. Self, "Muting Relays," *Electronics World*, July 1999.

SOURCES

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CadSoft Computer | www.cadsoftusa.com

NJ3FP6C Socket
Neutrik | www.neutrik.com

HD-650 Headphones
Sennheiser Electronic Corp. | http://en-us.sennheiser.com

MDR-35EX Headphones
Sony Europe, Ltd. |www.sony.co.uk

OPA2134 Op-amp
Texas Instruments, Inc. | www.ti.com

Editor's note: George Ntanavaras has a small quantity of PCBs (manufactured as shown in **Photo 3***) available for the construction of this amplifier. If you are interested in obtaining one, contact him at gntanavaras@gmail.com.*