EE 410 Linear Electronic Design
Spring 2009

Team Project Specifications
High-Efficiency Headphone Amplifier

I. Introduction

Now that the topic has been chosen for the team projects, it is time to better define the requirements. Your team may choose the design approach that you feel is most appropriate for solving this problem, but you must ensure that you will meet the attached specifications.

II. Problem Description

Listening to music from a portable music player on headphones is very common today. Many audio enthusiasts may be somewhat dissatisfied with the sound quality from portable music players, which may make the wrong design compromises in an effort to hold down costs, decrease size, improve battery life, or other criteria. Or they may want an external audio system that is capable of driving the headphones to higher volume levels.

The purpose of this project is to build a higher power yet efficient headphone amplifier that connects to a portable music player and produces high-quality audio reproduction at higher volume levels. An illustration of the system is shown in Figure 1 below:

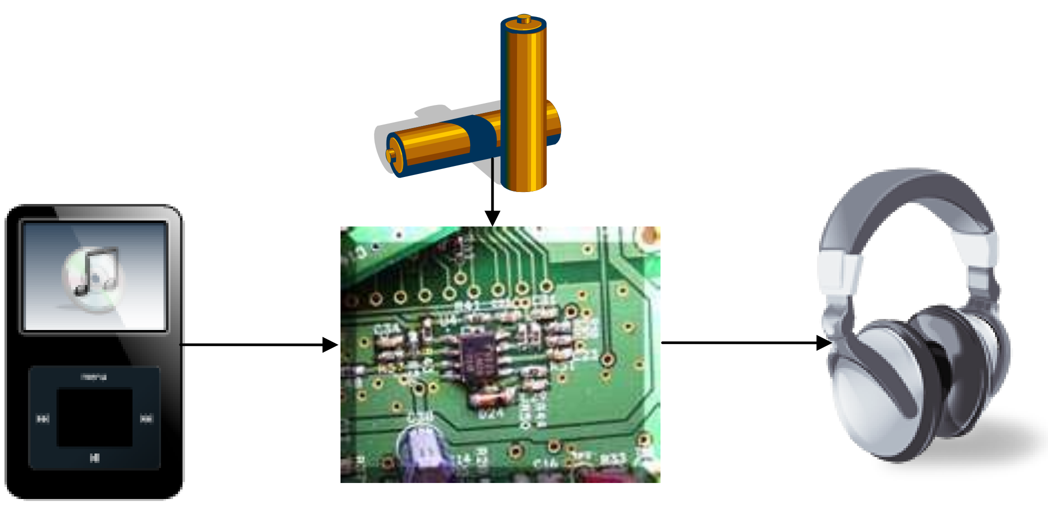

Figure 1

III Requirements Description

Starting with the requirement to deliver 100 mW per channel to a moderate-impedance (32 Ω) pair of headphones while being powered by a pair of AAA batteries we quickly determine that the available 3-V power supply rail voltage is insufficient to drive the headphones to the desired power output. Therefore this project may involve more than just audio amplifier design – it may also require design of a suitable switch mode DC-DC converter to develop the power supply rail voltages required for full power output. Unless, of course, you can think of alternative design approaches. Add to this the other requirements for low distortion, low noise and minimal power consumption and we quickly find out that the design task can become quite challenging.

Since this is an analog circuit design course and not a power electronics course and since we don't have the time or resources to delve into the finer details of switch mode DC-DC converter design, the use of commercial DC-DC converter ICs **is** permitted if required by your design approach. However, the use of commercial ICs specifically designed as headphone amplifiers **is not** permitted, even though there are a number of ICs that might work in this application. Part of the project learning experience is to determine the best internal architecture for a good stereo headphone amplifier, so discrete transistors or op amps are allowable but integrated headphone amplifier ICs are not.

Here is a quick summary of the minimum feature set for the headphone amplifier. Remember that the primary emphasis of the team project is on performance, not features:

- Stereo (two-channel)
- 1/8" stereo mini-jack input and output connectors
- Gain control
- Powered by two AAA batteries
- Long battery life; i.e. the absolute minimum power consumption

IV Details

Audio Amplifier

The main purpose of the audio amplifier is to provide the needed voltage and current to the low-impedance load. Some design considerations that you may need to consider include the method of coupling the headphones to the output stage (direct or capacitive). Direct coupling eliminates the need for large electrolytic capacitors but requires either bipolar power supplies or bridge-tied load configurations. Capacitive coupling works with unipolar power supplies, is simple, but has the disadvantage of needing large sized electrolytic capacitors. It also may result in a circuit that produces a loud "pop" when plugging or unplugging the headphones if care is not taken to keep the capacitor charged appropriately.

The use of bridge-tied load circuitry may also be a desirable option for producing the needed voltage swing across the load while operating at lower power supply voltage levels.

Power Supply

One of the first calculations that you should make is the required voltage swing at the output to deliver 100 mW to a 32 Ω load. If the value is larger than ±1.5 V, or 3-V unipolar, and cannot be produced by other methods (bridge-tied loads, for example) then you will probably need to design a step-up DC-DC converter to power your circuitry. When undertaking this task keep in mind that switch mode converters produce noise at the switching rate that can couple into audio circuitry. In order to minimize this coupling it may be necessary to use bypassing, filtering, and isolation to keep switching frequency components out of the audio amplifier. Even if the switching rate is above the audio passband, remember that intermodulation can occur between higher audio frequencies and the switching rate that could fall within the audio passband. Using higher switching frequencies is helpful but switching at lower rates generally uses less power. Switch mode converters are also a convenient way to "milk" every bit of life out of a battery while supplying a constant DC voltage to your circuitry. Without the DC-DC converter you will need to account for the fact that battery terminal voltage decreases as the battery discharges. With a DC-DC converter the current drawn out of the battery increases as the battery discharges, thus accelerating end of life. Tradeoffs abound when designing any electronic circuit so consider all of these factors when choosing a design approach.

Performance Challenges:

Some of the major design challenges will occur when trying to simultaneously meet specifications for noise, THD, operation from batteries, power consumption, and cost. Your design should not only attempt to meet the minimum requirements but also improve on some of them.

However, since the primary goal is minimum power consumption then it *may* not be wise to try to produce more power output than the minimum requirement. In fact, 100 mW into a typical pair of headphones is going to be very LOUD indeed. Instead the most successful design approach may be to make design compromises that result in your circuit just barely meeting all of the specifications except power consumption, which you should try to minimize by as much as possible.

When estimating costs, use the 100-piece price of each component from the Digi-Key catalog. All parts must be included in the cost estimate – even those that were obtained for free or as samples.

V Evaluation

Each iteration of your design must be measured objectively against the specifications on the next page and the results documented and compared. Read the footnotes following the Table of Specifications for additional details on measurement techniques.

Designs will be evaluated on whether they meet the specifications and on how well they perform. We will have a competition between teams to see which design performs the best. Objective measurement criteria will be used. Extra credits will be awarded as follows for each team that has the:

Lowest power consumption	+ 10 points
Lowest distortion	+ 5 points
Lowest material costs	+ 5 points

VI Specifications

The table on the next page is a definition of the design project in specification format. Your design must meet all specifications described by a **Min** or **Max** limit, and should attempt to improve upon those indicated as *design goals* with the (*) symbol.

Specifications, High-Efficiency Headphone Amplifier

Parameter	Min	Typ	Max	Units	Comment
Input Characteristics:					
Input Impedance		10 k		Ω	
Input level		–10	0	dBV	0 dBV = 1 V_{RMS}
Connector	1/8" stereo mini-jack				3-conductor
Output Characteristics:					
Maximum Output Level	100			mW	Without clipping
Rated Load Impedance		32		Ω	Typ. headphone Z
Output Impedance			3.2	Ω	Damping factor of 10
Connector	1/8" stereo mini-jack				3-conductor
Overall Characteristics (End-to-end measurement):					
Frequency Range	20		20 k	Hz	
Frequency Response			±1.0	dB	
Nominal Gain		20		dB	See note 1
Gain Adjustment Range	30			dB	See note 1
*THD			0.1	%	At 10 mW; see note 2
			1.0	%	At 100 mW; see note 2
Noise Density at output			–128	dBV/$\sqrt{\text{Hz}}$	See note 3
Power Requirements:					
Power Source		2 AAA cells			Alkaline batteries
Input Voltage			3	VDC	Consider voltage variation vs. time
*Power Consumption			400	mW	See note 4
*Battery Life	90			hours	See note 5
Cost:					
*Materials cost			$40		

Notes:

1. Nominal gain of the circuit with the gain control set at maximum. The gain control should be capable of reducing the gain by at least 30 dB from this value; i.e. from –10 dB to +20 dB. Being able to reduce the gain of the circuit below –10 dB is even better.
2. THD is to be measured with the circuit driven by a –10 dBV sinusoid at 1 kHz. Adjust the gain until the stated output power is achieved while driving a 32 Ω load. Measure with 3.0 VDC power supplied to the circuit.
3. Based on 80 dB SNR in a 20 kHz bandwidth with an average program level of 10 dB below full output. Noise is to be measured with the circuit gain adjusted to 20 dB and the inputs terminated with 1 kΩ resistors and the outputs terminated with 32Ω resistors. Measure the spot noise in a 1 Hz bandwidth at f = 1 kHz at the output. A plot of spot noise density vs. frequency measured from 20 Hz to 20 kHz will be most informative.
4. Power consumption is to be measured as follows. Drive both inputs simultaneously with a –10 dBV 1 kHz sinusoid and terminate both outputs with 32 Ω. Adjust the gain control for an output signal of 100 mW into each load resistor. Measure the total DC current supplied to the circuit when the circuit is powered by a 3.0 V power supply. Compute average power as V_{DC} x I_{DC}.
5. Estimate the battery life in hours based on the use of AAA alkaline batteries. Look up their capacity in mA-hr. Use an average current that is determined by assuming an average power consumption 10 dB below the maximum found in note 4 above. An actual measurement of the time needed for your circuit to discharge the battery down to 0.8 V per cell while operating is an even more valuable data point. Do this if you have the time needed to conduct the test.