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PHYS 2074

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Headphone Amplifier Construction Project

The purpose of this construction project was to build a headphone amplifier and to explain some of the physics behind how it works and what is going on in the device. Though the device does not have much practical everyday use, it is really cool to build and hear function. Figures 1 and 2 should be referred to for clarification of how the device works. Figure 1 shows the schematic for the power supply section of the device, and figure 2 shows the schematic for the amplification section.

To begin, the power supply section (Figure 1) will be explained. The LED (D1) indicates that the battery is switched to the "on" position. The LED also indicates that the battery is strong enough to supply the current needed to light the LED. It also serves to indicate a "low-voltage" condition for the battery. To say more, the diode characteristic of the LED must be known. It requires a minimum current, say I_{min}. Using Ohms Law, V=IR, the minimum voltage needed for the battery to light the LED is $V_{min} = I_{min} * 10$ kohm. This should be a minimum voltage for operation of the amp.

The R1/C1 combination stores power and serves to reduce modulation distortion due to current surges needed by the amp. The internal resistance of batteries is not low enough to keep the direct current rail voltage at the amp constant. If the rail voltage changes, it moves the bias voltage and current for the amp. This is called the "Q" point, for quiescent (quiet) mode. Moving the "Q" points changes the gain of the amplifier, thus distorting the audio out. The time constant for the RC combination is R1*C1 = 1.034 seconds. So the voltage is very nearly constant on time scales that are 1/10 times this amount, or 0.1 seconds or 10 Hz. The lowest audible audio frequencies are around 16 Hz, or 0.06 seconds; therefore, the voltage is basically constant. The power stored in each capacitor is 0.5 * C1 * V^2 = 0.5 * 220 uF * 9V * 9V = 8.91 mW. This would have to be enough to provide the power needed for the headphones less the power efficiency of the amp. The load resistance of the headphones is needed to figure out the exact numbers, but this project is not about speakers, it is about amplifiers.

Next, the amplification section (Figure 2) will be explained. The potentiometer is a resistive voltage divider used to adjust the input voltage to the amp. A bad feature of this design is that the amp noise goes up as you reduce the volume level.

The C2 and R2 combo prevents direct current from passing from the source to the amp and serves as a first-order high-pass filter. This is a filter that passes high frequencies well, but attenuates (reduces the amplitude of) frequencies lower than the cutoff frequency. 1/(R*C) is the cut-off radian frequency, and the response drops by a factor of 2 for each octave drop in frequency. $Omega_{cutoff}$ = 1/(100k * 0.1uF) = 100 radian/s. F_{cutoff} = omega / (2 * pi) = 16 Hz. So frequencies below 16 Hz will be attenuated. That is where the most power is so this protects the amp circuit.

The R2 resistor is also needed to provide a bias current path to ground. The op-amp will not function without that.

R5 resistor serves only to limit the output current for the case of trying to drive too small of a headphone load impedance for the op-amp chip. This is why it was considered optional, and was left out in this particular build.

The op-amp circuit is the heart of the design. The output voltage is a large gain multiple of the difference between the inputs. To make the calculations easier, assume an ideal op-amp of infinity gain and then the voltage difference at the input terminals is equal. In reality this is practically true. So V_{in} is at the (+) terminal and the same voltage appears at the (-) terminal. Also the input currents are practically zero for an op-amp design, so the output voltage can be calculated by knowing that the current through R4 equals the current through R3. This gives $(V_{out}-V_{in})/R4 = V_{in}/R3$ (Ohm's law) which can be solved to give the gain equation: $V_{out} / V_{in} = (R4 / R3) + 1 = (10k/1k) + 1 = 11$. This means that $V_{in} * 11 = V_{out}$. For example, if $V_{in}= 0.1$ V, then $V_{out} = 1.1$ V.

In conclusion, the project worked and the difference in the signal can be heard when using the amp. Actual measurements could not be taken for lack of proper equipment.

Figure 1

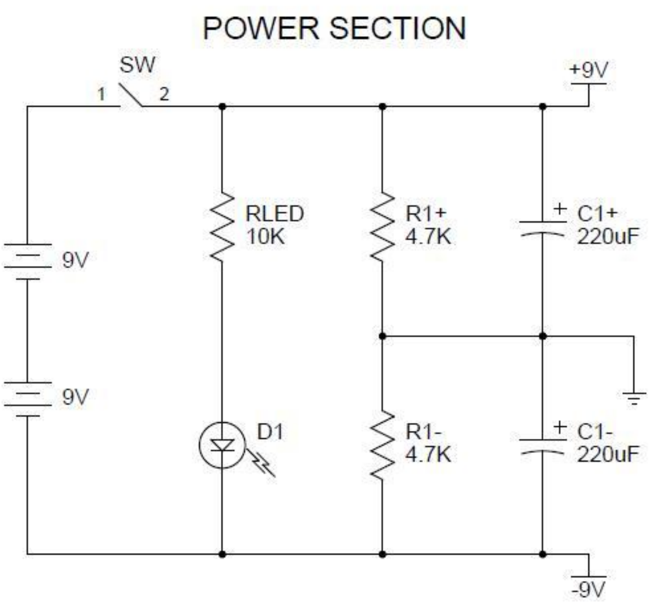
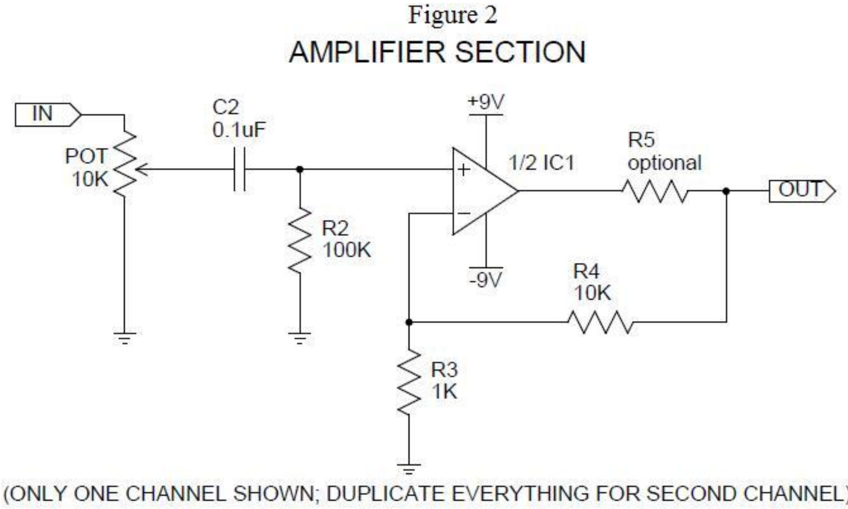


Figure 2



Sources

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