Electronics Implementation and Design: Building an audio power amplifier

Rhydian Windsor (9437658)
3rd year laboratory report. School of Physics and Astronomy, The University of Manchester. December 2016.
This experiment was performed in collaboration with George Needham.

An electronic audio power amplifier was designed to increase the power of an electronic audio signal from a mobile phone via a push-pull follower stage such that it could be played through an 8 Ω loudspeaker. The circuit was designed to have a theoretical maximum power gain of (7.67 ± 0.45) across all frequencies in the typical human audible range (20 Hz - 20 kHz). The amplifier was then constructed as a printed circuit board (PCB) and the gain was measured at varying input voltages and frequencies. A gain of 7.8 ± 0.2 was achieved for 100 Hz to 20 kHz, however gain was found to drop at frequencies of less that 100 Hz.

1 INTRODUCTION

Power amplification of electronic signals is a vital tool for experimental physicists, allowing the observation and analysis of low-power signals. This has a wide range of applications, for example in astrophysics and communication.

In this experiment an attempt is made to construct an efficient audio power amplifier. The circuit was designed to meet three key design parameters. The first is to amplify the audio output of a mobile phone to drive an 8Ω loudspeaker sufficiently for it to be easily audible. Secondly, the amplifier should not distort the input waveform and so constant gain should be achieved for all input frequencies and amplitudes, i.e.

$$V_{OUT}(t+\tau) = gV_{IN}(t) \tag{1}$$

should always hold. Here $V_{IN}(t)$ is the input voltage amplitude at time t and $V_{OUT}(t+\tau)$ is the output voltage amplitude at time $t+\tau$ (τ is the time taken for the signal to propagate through the circuit and should be independent of input signal frequency and amplitude[1]). g is the gain of the circuit and should also be independent of signal frequency and amplitude. Equation 1 also implies that the output audio signal should be directly proportional to the input signal. Thus, the third key design parameter is that the circuit does not produce background noise or distort the signals from the phone.

2 EXPERIMENT

Using an oscilloscope, the maximum output peak-to-peak voltage of the mobile phone used (iPhone SE) was found to be (1.0 ± 0.2) V. This was measured to ensure the amplifier met the design parameters for all possible input signals.

The architecture for the amplifier is shown in Figure 1. It consists of two parts: a non-inverting amplifier stage and a push-pull follower stage. The non-inverting amplifier stage consists an op-amp with a high-pass filter connected to its non-inverting input, the 1.5 kΩ resistor and the 10 kΩ potentiomenter. The potentiometer and adjacent 100 kΩ resistor together act as a variable resistor, allowing us to vary the voltage gain of the amplifier, given by

$$G = 1 + \frac{R_{Pot}}{1500}. \tag{2}$$

Here R_{Pot} is the resistance of the side of the potentiometer connected to the op amp's inverting input. This gives a theoretical maximum gain of (7.67 ± 0.45), where the uncertainty is due to the tolerance of the resistors.

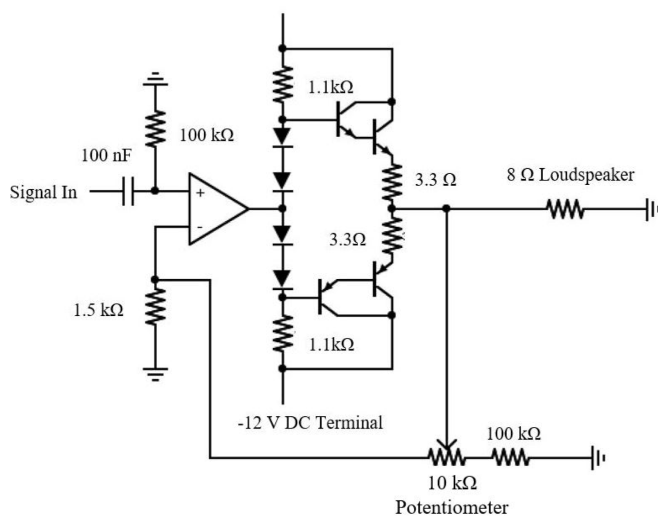

Figure 1: A schematic showing the general architecture of the power amplifier. The input feeds into a non-inverting amplifier, setting the voltage of the output.The signal then passes into the push-pull follower stage. This increases the current, amplifying output signal power such that it can drive the loudspeaker. ±12 V DC terminals power the amplifier and are adapted from a 24 V root mean square AC input at mains frequency.

The gain was chosen as the maximum achievable without high voltage clipping (flattening at the top and bottom of waveform due to an upper limit of potential across the loudspeaker[2]). As well as voltage amplification, the non-inverting amplifier also uses negative feedback to remove distortions in the signal caused by the push-pull follower stage. The output of the push-pull follower stage is compared with the input to the inverting amplifier and the output signal is then adjusted such that any distortions are removed[3]. The high-pass filter has a cut-off frequency of 15 Hz and attenuates DC signals being fed into op amp which would alter the amplifier's electronic properties.

The push-pull follower stage consists of the components between the op amp output and the feedback loop. This stage amplifies the current of the signal but does not change the amplitude and hence the power of the signal is amplified. This current is achieved by the use of Darlington pairs, which provide a greater current gain than single transistor. The total gain is equal to the product of the current gain of the component transistors. Diodes are added before the Darlington pair to eliminate crossover distortion in the signal. These diodes hold the base of the Darlington pair at a potential above the emitter such that one of the transistors is active, even for very small audio signals.

Figure 2 shows the power supply used for the amplifier. Four diodes are configured as a full wave bridge rectifier, which takes the modulus of the AC signal, ensuring the one terminal is always at a higher potential than the other. 1 mF smoothing capacitors are introduced after the rectifier, responsible for creating a DC signal. This signal still has a ripple current which is removed by voltage regulators which ensure a constant ± 12 V DC output. Capacitors are added after the regulators stabilise the regulators, providing a low impedance route to ground for any AC signals coming from the regulators.

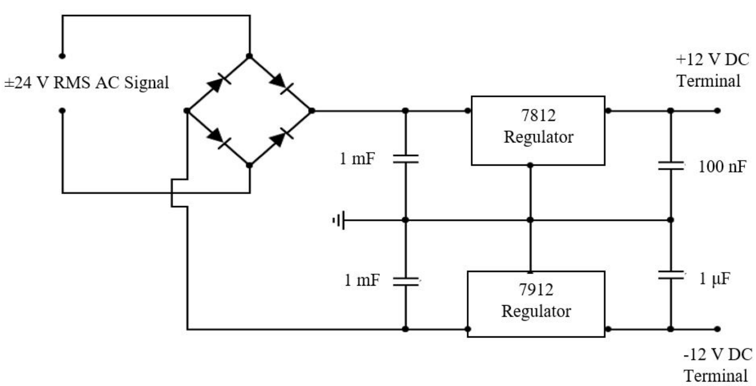

Figure 2: A schematic showing the architecture of the power supply. A ± 24 V AC supply feeds into a full wave bridge rectifier. The signal is then converted to DC by 1 mF smoothing capacitors and regulators then remove any ripple current.

3 RESULTS and DISCUSSION

The circuit was printed as a PCB and the gain was tested for sinusoidal signals of varying frequencies. A graph of the the maximum gain profile of the amplifier for a 1 V peak to peak input is shown in Figure 3. It can be seen that the gain is approximately constant across most of the audible range. However, it appears to be lower for 20-100 Hz. This is likely due to the high-pass filter of cut-off frequency 15 Hz which will attenuate signals of these frequencies. This hypothesis could be tested by using a filter with a different cut-off frequency and observing the new gain profile produced.

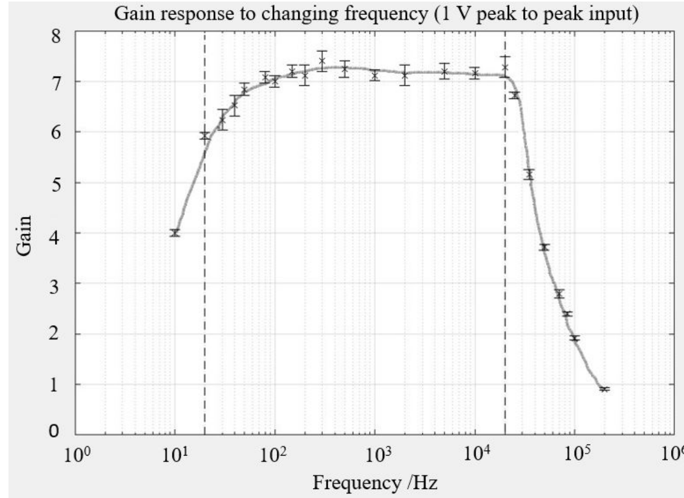

Figure 3: A graph plotting the maximum achievable gain of the power amplifier against input frequency of a 1 V peak to peak sinusoidal input. The dotted vertical lines show the human hearing range (20 Hz - 20kHz).

From 100Hz to 20 kHz the gain was measured be fairly constant, varying between the between 7.6 V and 8 V. This is consistent with theoretical predications of a gain of (7.67 ± 0.45). By using feedback resistors of lower uncertainties a more accurate theoretical prediction of gain could be obtained and any gain distortions could be more accurately observed. The gain profile shown in Figure 3 was similar for all input amplitudes from 0 V to 1 V peak to peak. Beyond this clipping was observed. This fits with the specification of building an amplifier for a source with a maximum output amplitude of 1 V peak to peak.

4 CONCLUSIONS

An audio power amplifier designed to amplify an audio signal of 1 V peak to peak maximum amplitude with a variable gain of 1 to 7.67. The circuit was then implemented as a PCB and the gain was measured with varying input frequencies and amplitudes. It was found that the amplifier had a approximately constant gain of 7.8 ± 0.2 for input frequencies in the range of 100 Hz to 20 kHz, however the gain was less in the frequency band of 20 to 100 Hz. No significant distortion was found for monochromatic signals in the audio range for amplitudes of less that 1 V peak to peak, above which clipping was observed.

REFERENCES

[1] Grob, B. (1984). *Basic Electronics.* 5th ed. New York: McGraw-Hill Book Company. p. 574.

[2] Horowitz, P. and Hill, W. (1989) *The Art of Electronics*. 2nd ed. Cambridge. University of Cambridge Press. p. 70.

[3] Castoldi, A. (2011) *Analysis of circuits with negative feedback.* [online] Available at http://home.deib.polimi.it/castoldi (Accessed 14 Dec 2016)

[4] Horowitz, P. and Hill, W. (1989) *The Art of Electronics*. 2nd ed. Cambridge. University of Cambridge Press. p. 94.