Electronic audio power amplifier design and implementation using discrete and integrated components

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An electronic power amplifier for use in the audio frequency range was designed, simulated, built and tested. Simulation was done using the iCircuit software package. The circuit was subsequently built on breadboard and then finally on a PCB. Testing was carried out with oscilloscopes and digital multimeters. The circuit included a ±12V regulated power supply, operational amplifier and push-pull stage. Voltage gain was provided by the operational amplifier, current gain by the push-pull, which together gave power gain. At operating conditions, voltage gain is a factor of about 9.

1. INTRODUCTION

Physics research often requires signal amplification to allow easier measurement, with less effect from noise and background signal [1]. Electronic amplification is done using basic components such as resistors, capacitors, diodes, transistors and operational amplifiers (op amps), along with more complex components like regulators. When using a power amp, the aim is to have higher output than input power: power gain. This is achieved by having voltage gain, current gain, or both. The first stage in a power amp is a regulated power supply, which provides current to a push-pull stage and also the maximum output voltage to the op amp. The principle behind a push-pull is two transistor amps, which provide current gain whilst replicating the input signal. Similarly, an op amp provides voltage gain whilst replicating the input signal. Together, a regulated power supply, push-pull and op amp form a power amp. Alongside building a circuit, one has to simulate components to check that they are performing as expected and to compare experimental results with theory. An example of a circuit design and simulation package is iCircuit [2]. Important characteristics for an audio amp are its frequency response and gain as a function of input level. Ideally, gain would be constant across the audio frequency range (about 20 Hz to 20 kHz) and independent of input level. However, gain cannot be constant for an arbitrarily large input as a power supply sets a maximum possible output voltage, leading to an effect called clipping once the maximum input voltage is exceeded. In real applications, electronic circuits are built on a Printed Circuit Board (PCB) to reduce the circuit's physical size and number of wires [3]. DesignSpark [4] is a common PCB design package.

2. EXPERIMENT

Figure 1 shows a schematic diagram of the final amp, without the power supply circuit used to provide the +12 V and −12 V in the diagram. iCircuit does not have regulators in its library, therefore the power supply could not be simulated. Regulators have specific voltage requirements, such as outputting +12 V if the input voltage is between +14.5 V and +25 V [5]. This means that the mains supply ripple has to be reduced by including a capacitor, so that the discharge time keeps the regulators' input voltage in the desired range. 3300 μF was chosen as the largest value capacitor available and able to fit comfortably on a PCB. After each regulator, another capacitor is included for smoothing. Here, a value of 10 μF was sufficient.

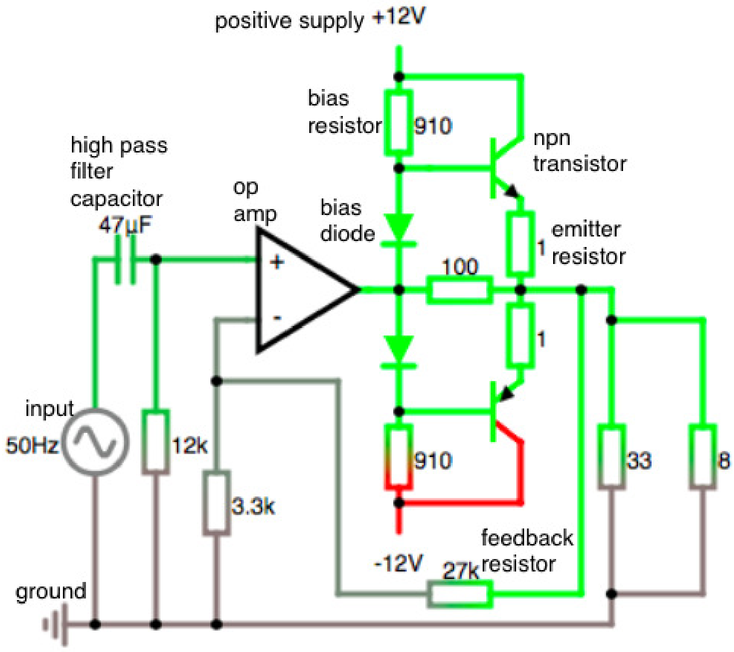

Figure 1: Schematic of the experimental setup. The unlabelled components are a negative −12 V supply, 12 kΩ resistor to complete the high pass filter, 3.3 kΩ resistor to complete the feedback loop, 100 Ω bridge resistor between the bias diodes and emitter resistors, pnp transistor, 8 Ω resistor to simulate a speaker and 33 Ω resistor in parallel with the speaker.

The component with the biggest impact on voltage gain is the feedback resistor. A simple non-inverting amp has a voltage gain of $1 + R_f/R_2$, where R_f is the 27 kΩ feedback resistor and R_2 is the 3.3 kΩ resistor which completes the feedback loop. The values of R_f and R_2 were chosen to give a voltage gain slightly under 10. A high pass filter before the op amp modifies the voltage gain to $\frac{(1+R_f/R_2)f/f_c}{\sqrt{1+(f/f_c)^2}}$, where $f_c = 1/(2\pi R_1 C_1)$ is the filter cutoff frequency, with R_1 and C_1 being the high pass filter resistor and capacitor respectively. To give a voltage gain as constant as possible across the audio range, f_c should be as small as possible. C_1 was chosen as 47 μF, the largest non-electrolytic capacitor available, to avoid polarisation problems. Then, R_1 was chosen as the largest resistor which gave a stable output. In the push-pull, small bias resistors would decrease the current into the transistor bases, but more of the 24 V maximum swing would be available at the output, with the opposite true for large bias resistors. Therefore, 910 Ω was chosen as a compromise between these conditions. In operating conditions, it was found that the circuit overheated, which led to the inclusion of transistors heat sinks and small thermal emitter resistors. A bridge resistor between the bias diodes and emitter resistors improves operation in the crossover region when the npn transistor is switching on or off and the pnp transistor is doing the opposite. A 33 Ω resistor is included in parallel with the speaker to reduce the current going to the latter. It was found that without a resistor in parallel, output was loud but distorted. Including a resistor in parallel reduced volume, but significantly improved quality.

3. RESULTS and DISCUSSION

The frequency dependence of voltage gain is shown in Figure 2 at 300 mV input voltage amplitude. Within the audio range 20 Hz to 20 kHz, voltage gain is nearly constant. 20 Hz and 20 kHz are rough limits to the audio range, few people can hear up to 20 kHz. Babies may hear up to 20 kHz, but the upper limit decreases with age, and can decrease below 10 kHz [6]. 20 Hz is similarly an extreme lower limit. As one goes to higher frequencies than 20 Hz, or frequencies lower than 20 kHz, the voltage gain approaches the theory and simulation values. Considering the non-fixed limits of the audio range, the voltage gain against frequency result is improved. Additionally, most music stays away from the audio range limits. Low frequency corresponds to bass and high frequency to high pitch tones, which both become uncomfortable to humans. This fact again improves the voltage gain with frequency result when the amp is used for its main application: playing music. Voltage gain decreases quicker than expected at low frequency, but the decrease only has a large effect outside the audio range. At high frequency, measurements disagree with theory and simulation. This is due to the op amp slew rate, which is the maximum V/s it can output. Once the frequency is too high, the op amp will not be able to output the desired voltage at the required rate, therefore the output voltage decreases.

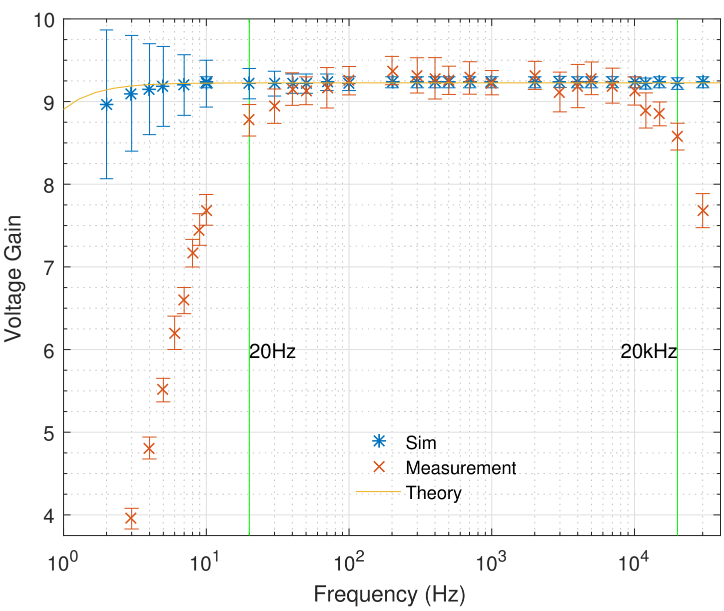

Figure 2: Frequency dependence of voltage gain at a constant input voltage amplitude of 300 mV.

Figure 3 shows the input voltage dependence of voltage gain at 440 Hz. 440 Hz is a common musical note, therefore it is a typical frequency when the amp is used for music. Between input voltage amplitudes of 100 and 450 mV, voltage gain is roughly constant. Below 100 mV voltage gain drops because the amp built is a power amp, therefore it behaves better for high power applications. If one wanted an amp that behaved better for small signals, one would build a small signal amp [7]. Having greater voltage gain for higher input voltage than lower input voltage is not a bad thing, it means the volume difference between high and low inputs will also be amplified. In the simulation, the output starts clipping above the last data point (475 mV). In real measurements, deciding when the output signal has started clipping is slightly subjective. It was deemed that the output had started clipping by 450 mV, which explains why voltage gain had decreased by this point. The input amplitude at which voltage gain is at its highest is 300 mV, which is why Figure 2 measurements were made at 300 mV. From Figure 2, the frequency at which voltage gain is highest is around 400 Hz, which justifies making measurements for Figure 3 at 440 Hz.

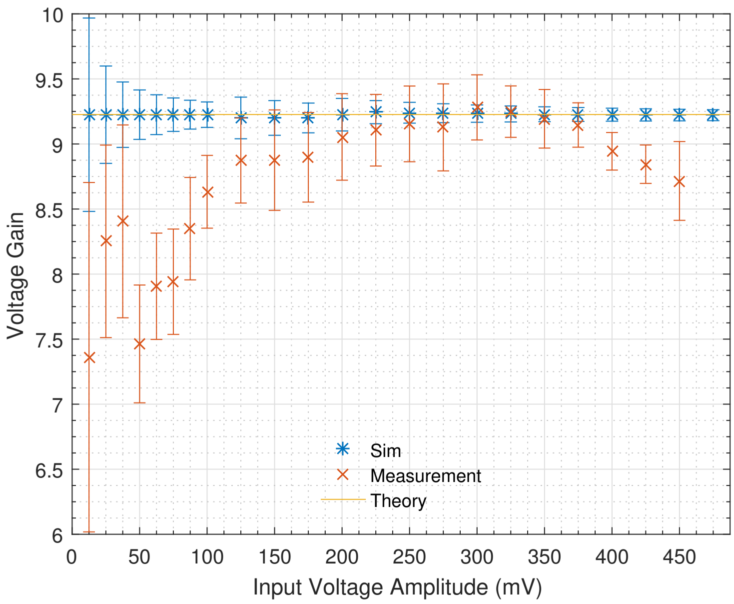

Figure 3: Input voltage amplitude dependence of voltage gain at a constant frequency of 440 Hz.

4. CONCLUSIONS

The final amp has a voltage gain of a factor of around 9 for the whole of the audio range at 300 mV input amplitude. At a frequency of 440 Hz, the amp has a voltage gain of a factor of around 9 for input amplitudes between 100 and 450 mV. These results show that the amp is suitable for playing music.

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