Electronics I

Audio Amplifier Design Project

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General Description

This power amplifier is designed for use in low voltage applications. This 2 channel amplifier is supplied by ±13.8 voltage sources. For audio amplification applications, each channel can output to one speaker. The voltage gain of this system is 12. All of the power transistors are heatsinked to withstand the heat generated while amplifying the current in the output stage. The amplifier can easily operate in ambient temperatures of 35 °C without fans.

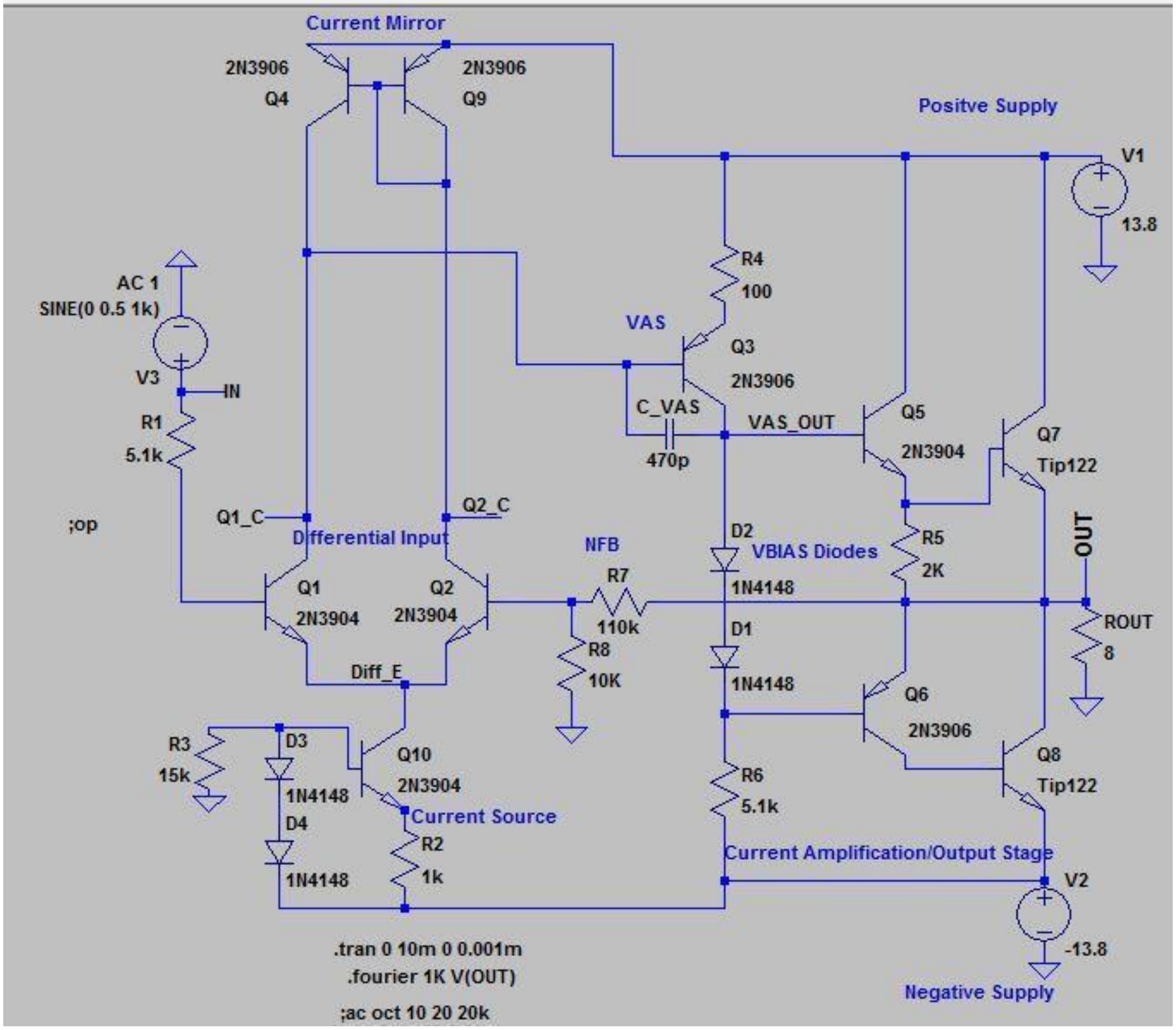
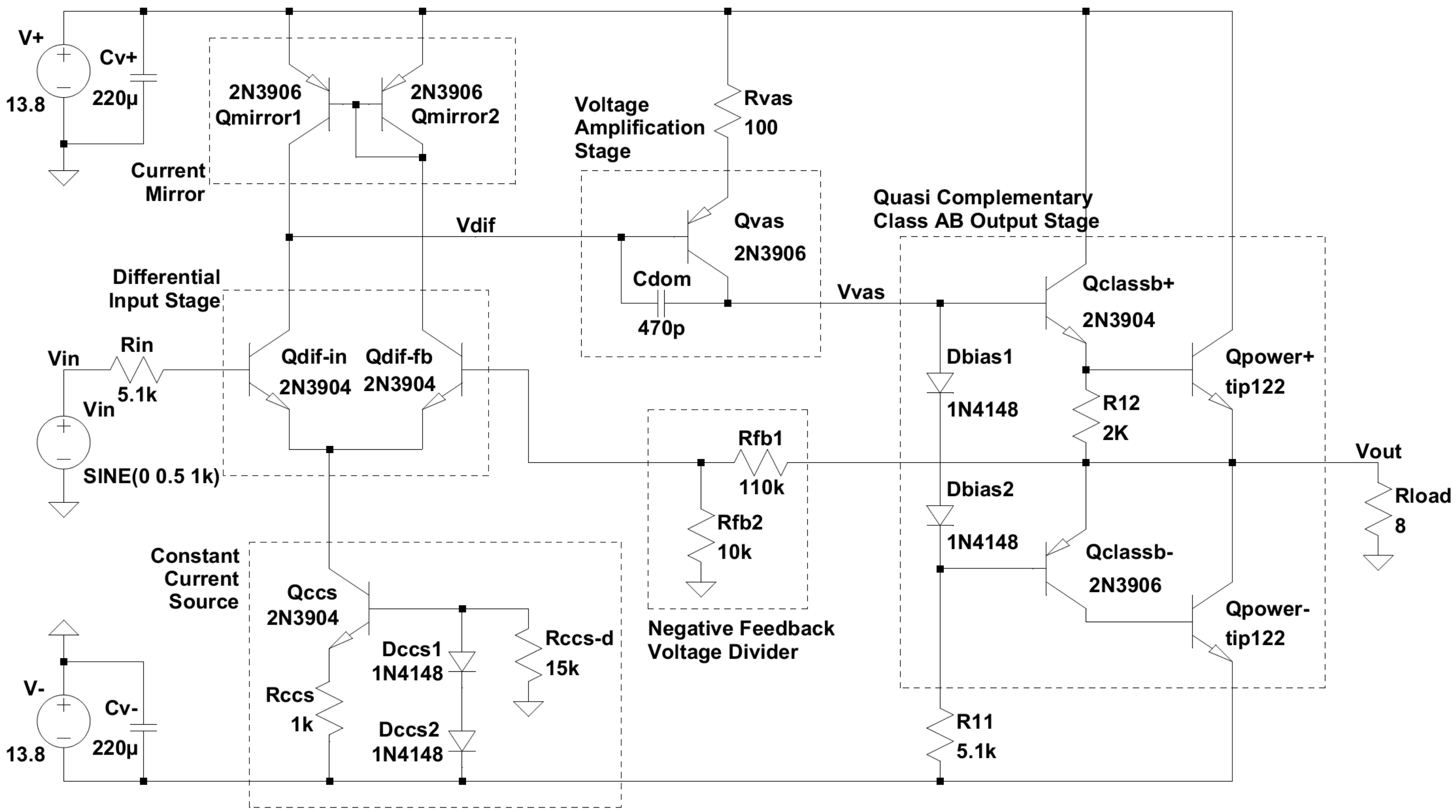


Figure 1A. Circuit Diagram


V+
13.8
Cv+
220µ
2N3906
Qmirror1
2N3906
Qmirror2
Current
Mirror
Vdif
Voltage
Amplification
Stage
Rvas
100
Qvas
2N3906
Cdom
470p
Vvas
Quasi Complementary
Class AB Output Stage
Qclassb+
2N3904
Qpower+
tip122
Dbias1
1N4148
R12
2K
Vout
Rload
8
Dbias2
1N4148
Qclassb-
2N3906
Qpower-
tip122
R11
5.1k
Differential
Input Stage
Vin
Rin
5.1k
Vin
SINE(0 0.5 1k)
Qdif-in
2N3904
Qdif-fb
2N3904
Rfb1
110k
Rfb2
10k
Negative Feedback
Voltage Divider
Constant
Current
Source
Qccs
2N3904
Rccs
1k
Dccs1
1N4148
Dccs2
1N4148
Rccs-d
15k
V-
13.8
Cv-
220µ

Components List

Resistors

Reference	Resistance
R1	5.1K Ω
R2	1 K Ω
R3	15 K Ω
R4	100 Ω
R5	2 K Ω
R6	5.1 K Ω
R7	110 K Ω
R8	10 K Ω

Capacitors

Type	Capacitance
Ceramic	470 pF

Diodes

Reference	Type	Part Number
D1	OnSemi	1N4148
D2	OnSemi	1N4148
D3	OnSemi	1N4148
D4	OnSemi	1N4148

Transistors

Reference	Manufacturer	Part Number	Description
Q1	Phillips	2N3904	NPN BJT
Q2	Phillips	2N3904	NPN BJT
Q3	Phillips	2N3906	PNP BJT
Q4	Phillips	2N3906	PNP BJT
Q5	Phillips	2N3904	NPN BJT
Q6	Phillips	2N3906	PNP BJT
Q7	Fairchild	TIP122	NPN Power Transistor
Q8	Fairchild	TIP122	NPN Power Transistor
Q9	Phillips	2N3906	PNP BJT
Q10	Phillips	2N3904	NPN BJT

Input Stage

The input stage to this amplifier has 3 main parts: a differential BJT pair, a current mirror BJT pair, and a constant current source. Connected to the bases of the BJTs in the differential pair are the input signal and the negative feedback coming from the output. The differential pair generates an error signal that drives the output.

To bias the differential pair, we used a constant current source. Based on a recommendation from Douglas Self, the current source was designed to draw around 600 μA from the differential pair (0.7 V / 1 kΩ = 700 μA). In designing the current source, the forward voltage on the diodes and the transistor’s V_{be} were assumed to be 0.7 V. The spice simulation puts the current source at 517 μA.

Due to the variable nature of the values of BJT beta, in order to keep the differential pair operating correctly (i.e. with equal collector currents on both transistors) we added a current mirror. Although this is still not perfect because the betas of the current mirror transistors are not matched, it does improve the symmetry of the differential pair.

Voltage Amplification Stage

The Voltage amplification stage consists of a BJT in the common emitter configuration with the base and collector connected by a capacitor. As the voltage at the base changes, so does the voltage across the 100 Ω resistor on the emitter. This in turn changes the current through the emitter and thus though the collector. The changing current causes a much larger changing voltage across the 5.1 kΩ resistor, which then leads to the output stage. However, the actual gain of the voltage stage is determined by the global negative feedback that drives the second transistor in the differential input stage.

The 470 pF capacitor creates local negative feedback (only for AC) that helps prevent oscillations and other unwanted distortion at higher frequencies. Although we initially used a value of 100 pF (as recommended by Self), while building the circuit we found that increasing its value to 470 pF virtually eliminated some distortion that did not show up during Spice simulations. Doing this had very little impact on gain or frequency response.

Output Stage/Current Amplification Stage

The output stage is used to amplify current in order to deliver adequate power to the load. Our initial design consisted of a class AB output stage using two Darlington pairs to achieve the desired current gain. However, due to the actions of other design teams, the ECE department ran out of TIP42C PNP power transistors. To cope with this problem, we redesigned the output to use on Darlington pair and one Sziklai pair, meaning both of the power transistors could be NPN. Unfortunately, at this point TIP41C transistors (the NPN power transistors) were also nowhere to be found. Instead we used TIP122 NPN power transistors, which were still available. Since TIP122 are themselves Darlington pairs, the output stage amplified current too much, drawing more than 1A from both the positive and negative rail. To fix this we reduced our total gain by modifying the global negative feedback. The change drew only 800 mA peak from each rail, and of course supplied less power to the load.

Negative Feedback

The negative feedback resistors are responsible for controlling the gain of the amplifier. The resultant gain is equal to one plus the the resistor in series with the feedback line divided by the resistor going to ground. As mentioned previously, we changed our gain from the 23 times recommended by Self to 12 times so as not to draw too much current.

Other Features

After obtaining a working prototype on a breadboard, we decided to create the final two channels on a perfboard for increased reliability and sturdiness.

In building the circuit, there was a significant amount of distortion on the peaks of the output waveform. To fix this, we added 220 μF between both rails and ground to stabilize the power supply input voltages.

The first part of the constant current source that biases the differential input pair (namely the two diodes and 15 kΩ resistor) was only built once. The voltage created at the base of the transistor was then used in the second channel to recreate the same current source using fewer parts.

We added a potentiometer between the input for both channels and the amplifiers themselves. The left lead on the pot was connected to the input signal, the right to ground, and the middle to the amplifier. This configuration has the pot act as a variable voltage divider, allowing logarithmic adjustment of the input signal, and thus also the output signal.

Simulation Results

Gain

These simulations are the result of an input signal of 0.500 Volts amplitude with a frequency of 1 kHz. The negative feedback provides a gain of R7/R8 + 1. In this circuit, that would result in a gain of 12. Figure A below shows the measured simulated signal at the input and output. 6 Volts divided by 0.500 volts yields a gain of 12.

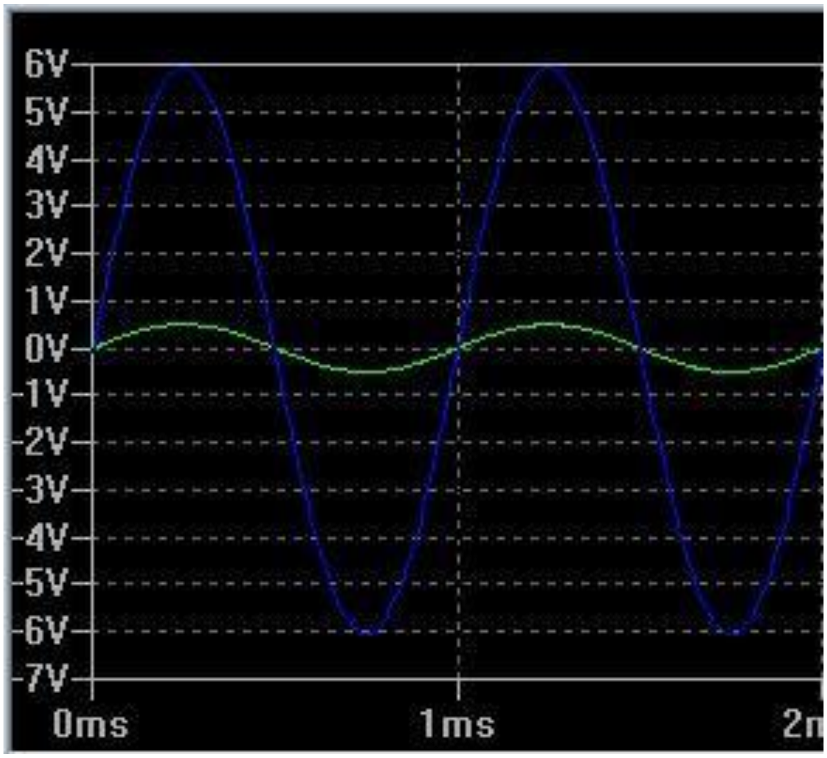


Figure A. Vout and Vin

Total harmonic Distortion

When amplifying an input signal, there should be very little distortion on the output signal. In order to measure this in simulations, LTSpice offers users the ability to perform a Fourier Analysis on signals in a circuit. The spice directive has the syntax of ".fourier Frequency Node" where Frequency is the frequency of the signal traveling through the circuit and Node is the node at which the fourier analysis is performed. For our purposes, we want to measure the THD at the output node. According to the simulations, at 1kHz with an input signal having an amplitude of 0.5 Volt, our output signal had a THD of 0.036467%. The goal for the project was to have a THD of less that 0.1%.

Power Dissipation

In order for the audio amplifier to function properly, all of the components need to be in good working order. To keep them there, specific components cannot exceed certain power dissipations. All of the resistors except for the output resistor can only handle 0.250 Watts. All of the non-power transistors (2N3904 and 2N3906) can only handle 0.600 Watts. However, the power transistors used in the current amplification stage, can handle up to 65 Watts with a Case temperature of 25 Degrees Celsius.

Figure B, shows the power dissipated by each of the powered transistors. This measurement is important because if left on for a long period of time, the power transistors would eventually pass their safe operating temperature , assuming they weren't heatsinked properly. Every 10 degrees Celsius above the max operating temperature a device goes decreases the life of the device by half. As can be seen below, our TIP122 power transistors reach a peak of 6.2 Watts, with an average power dissipation of 2.26 Watts. The red curve shows the power dissipated in the Q7 transistor, while the green curve shows the power dissipated in the Q8 transistor.

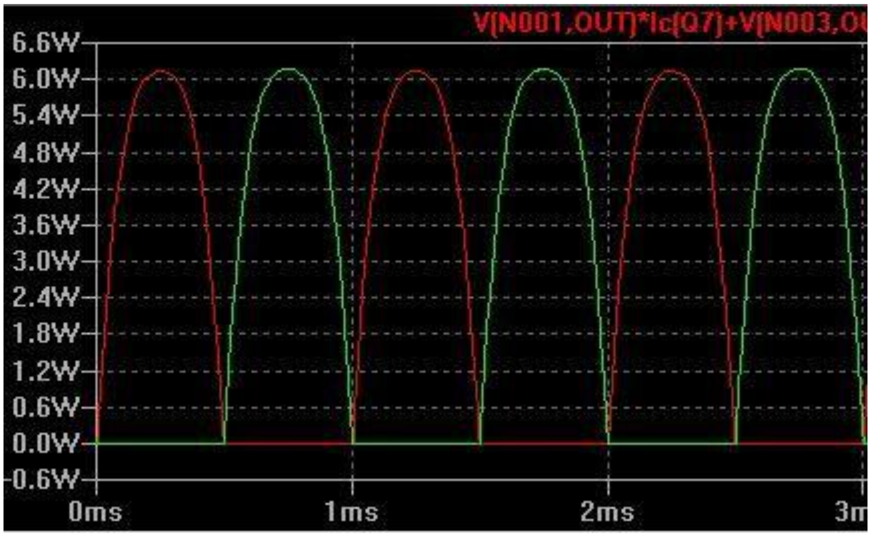


Figure B. Power Dissipated in Power Transistors

Heatsinking

If the power transistors were operated without heatsinks while dissipating 2.26W, they would fail very quickly by passing their maximum junction temperature of 150°C. According to the TIP122 datasheet from Mouser, it has an R_{j-c} of 1.92 °C/W and R_{c-a} of 62.5 °C/W. Assuming a worst-case ambient temperature of 35°C, the transistors would reach a T_j of 180.6°C.

A heatsink is obviously required to prevent damage to the transistors. According to Vishay, the average R_{c-s} of the TO-220 package and a heat sink without thermal grease can be up to 2 °C/W depending on how tight the connection is. To keep T_j at an acceptable level, here chosen to be 125°C, a heat sink with a maximum R_{s-a} of 35.9 °C/W is required. The heat sinks available from the ECE department, namely model 504222B00000G, have an R_{s-a} of 6.4, which is well within our requirements. Using these heat sinks, T_j will only reach 58.3°C.

The TIP122 is able to dissipate less power the hotter it gets, so our previous assumption of a maximum of 65W is inaccurate. According to the data sheet, at T_c of 54°C (what it will be using the aforementioned heat sink) the transistor can dissipate 48.75W, which is well above our requirement of 2.26W.

Construction Issues

When we constructed our audio amplifier on a breadboard using the circuit diagram .The breadboard circuit amplified the input extremely well, with very good frequency response within the range of 20 Hz to 20 kHz. Various types of music used as an input into the amplifier. The amplifier performed to its design, replicating the input sound at a higher signal strength with very little distortion.

The circuit was then replicated on perfboard, with two channels on the perfboard. The two channels were constructed with reference to the circuit diagram constructed in spice, not from the breadboard. Tests were performed on both channels with the signal generator. Both channels amplified input signals to the designed amplitude.

The audio amplifier on the perfboard stopped functioning however when a potentiometer to the perfboard. The potentiometer caused distortion on the input signal to the amplifier. The potentiometer was then removed from the perfboard, however the amplifier was no longer functioning.

The potentiometer was then connected to the breadboard circuit . The breadboard amplifier stopped functioning. We were never ever able to successfully construct a working amplifier after the first three ceased function.