Design and Analysis of an Audio Amplifier using BJT Transistors (December 2019)

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***Abstract*—This page describes an audio amplifier capable of supplying 30mW of power to a 32Ω load corresponding to a *Listen Technologies Corp.* model LA-161 Single Ear Bud is presented. The audio amplifier is broken down into five stages: volume control, bias network, NPN common emitter amplifier with an emitter resistance, PNP emitter follower amplifier, NPN emitter follower amplifier. In order to design this audio amplifier, we were given a certain set of requirements to follow. We were also given a set of output parameters and they are as follows: Quiescent Power Supply Current less than or equal to 200mA, Small-Signal Voltage Gain Deviation less than or equal to .1 dB, 1-dB Output Compression Point greater than or equal to 56.8 dBmV RMS. We were able to simulate our audio amplifier through circuit design software and plot our system for verification of parameters. All five stages and our simulations of our audio amplifier are described.**

***Index Terms*—Bipolar transistor circuits, Linear circuits, Operational amplifiers**

I. INTRODUCTION

THE goal of this project was to design an audio amplifier circuit capable of supplying 30mW of power to a 32Ω load which is to represent a *Listen Technologies Corp.* model LA-161 Single Ear Bud. The circuit was broken down into 5 stages that were designed and simulated using LTSpice.

The first stage of the circuit is a potentiometer realized with a voltage divider to control the volume of the input signal. The next stage is a voltage divider biasing network to set the DC operating point of our subsequent stages. Following the bias network is a common emitter BJT to create a voltage gain stage. A PNP emitter follower and an NPN emitter follower are then used in the output stage of the circuit in order to lower the voltage and increase the current to drive our relatively small load.

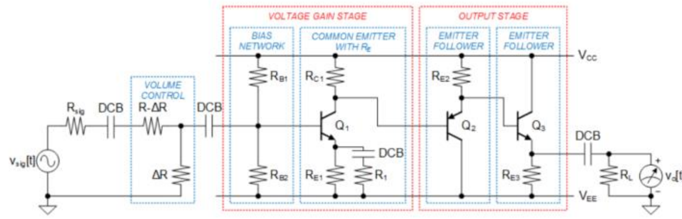

Figure 1. Audio amplifier consisting of five stages: (i) volume control, (ii) bias network, (iii) NPN common emitter amplifier with an emitter resistance, (iv) PNP emitter follower amplifier, and (v) NPN emitter follower amplifier.

Design Constraint	Symbol	Nominal Value
Operating Temperature	T	300 K
Top-Rail DC Supply Voltage	V_{CC}	+6 V
Bottom-Rail DC Supply Voltage	V_{EE}	-6 V
Audio Signal Frequency	f_m	261.626 Hz
Signal Generator Output Resistance	R_{sig}	50 Ω
Load Resistance	R_L	32 Ω

Table 1. Design constraints

II. STAGES OF AMPLIFIER DESIGN

A. *Volume Control Stage*

The first stage we had to design was the volume control stage. In power amplifiers the volume control is an input sensitivity control. This will have no direct effect on the output stage of the amplifier, but rather determines how much resistance there is to the incoming input signal getting to the voltage gain stage. The purpose of regulating this input signal is to effectively turn the amplifier down.

This is designed using a simple voltage divider, which mimics a potentiometer, that controls the volume of the audio signal. The voltage divider was designed such that the sum of the two resistances would equal a chosen value of R.

$$R = (R - \Delta R) + \Delta R \qquad (1)$$

When designing for our audio amplifier, we design around the maximum volume, i.e. where RV1 in figure 2 is zero.

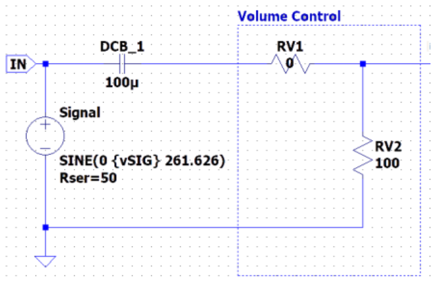

Figure 2. Volume Control Stage

B. *Bias Tree Stage*

A voltage divider biasing is commonly used in the design of a bipolar transistor amplifier circuits. Transistor Biasing is the process of setting a transistors DC operating voltage or current conditions to the correct level so that any AC input signal can be amplified correctly by the transistor. Establishing the correct operating point requires the selection of bias resistors and load resistors to provide the appropriate input current and collector voltage conditions. The biasing point operates on it being either "fully-ON" or "fully-Off" along its DC load line. This central operating point is called the "Quiescent Operating Point", or Q-point. This method of biasing the transistor greatly reduces the effects of varying beta, (β) by holding the base bias at a constant steady voltage level allowing for best stability.

By performing large circuit analysis on the common emitter and bias tree stages, we were able to determine that a resistor ratio of 6.65:1 would bias the common emitter base at around -4.5V.

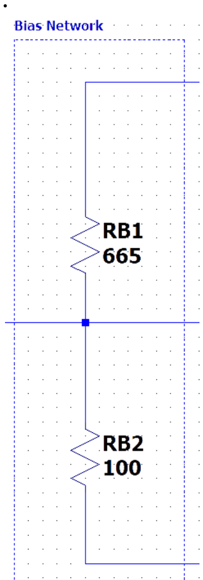

Figure 3. Bias Network Stage

C. *Common Emitter Stage*

The common emitter amplifier is one of three basic single stage bipolar junction transistors and is used as a voltage amplifier. The base terminal will accept the input while the output is collected from the collector terminal. The emitter terminal is common for both the terminals. The base bias voltage is supplied from our bias tree network previously discussed. The Rc1 resistor is used at the output and is typically called the collector resistance. The Re1 resistor is used for thermal stability, while DCB_3 capacitor (coupling capacitor) is used to separate the AC signals from the DC biasing voltage.

The current gain of common emitter amplifier is defined as the ratio of change in collector current to the change is base current. The voltage gain is defined as the product of the current gain and the ratio of the output resistance of the collect to the input resistance of the base circuits.

$$\beta = \frac{\Delta Ic}{\Delta Ib} \tag{2}$$

$$Av = \beta(\frac{Rc}{Rb}) \tag{3}$$

We determined the resistance value Re as the current gain, alpha, divided by the desired collector current, Ic. We can also find Rc by dividing 0.3V by the collector current. We can also find RC by:

$$Re = \frac{\alpha}{I_c} \tag{4}$$

$$Rc = (\frac{0.3V}{Ic}) \tag{5}$$

These give us values of 99Ω and 750Ω, for Re and Rc, respectively.

The advantages of using a common emitter amplifier is as follows: it has a low input impedance and it is an inverting amplifier, the output impedance of this amplifier is high, the amplifier has highest power gain when combined with medium voltage and current gain, and the current gain of the common emitter amplifier is high.

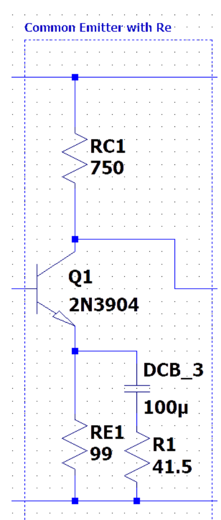

Figure 4. Common Emitter Stage

D. *PNP Emitter Follower Stage*

The PNP common collector, or emitter follower, acts as a voltage buffer between the common emitter stage and the PNP emitter follower. It has a relatively high input impedance and a low output impedance. This allows for a high voltage input and a high current output. For Re2 we choose a moderately small resistor value to create a small voltage drop, but an increased current. We determined 150Ω to be an enough value for our purposes.

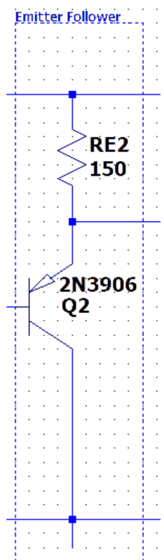

Figure 5. PNP Emitter Follower Stage

E. *NPN Emitter Follower Stage*

The NPN emitter follower comes after the PNP emitter follower. The purpose of this second emitter follower is to offset the V_{BE} voltage offset of the PNP transistor with the V_{BE} voltage of the NPN transistor. Both the NPN and PNP emitter followers allow for the proper power to be delivered to the load and give an overall voltage gain close to unity. Again, a small resistor value decreases voltage but increases the current gain. A resistor value of 90Ω was used.

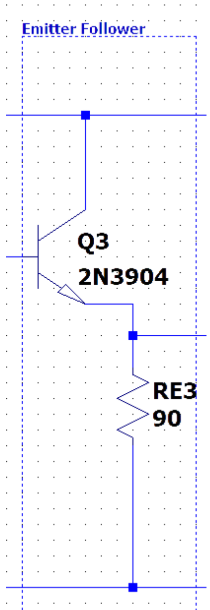

Figure 6. NPN Emitter Follower Stage

III. Summary and Results

After design considerations were finalized, the circuit was simulated and analyzed to find certain figures of merit and confirm that the design operates within the specified parameters. As shown in table 3, the quiescent power supply current, small-signal voltage gain deviation, and 1-dB output compression point are all within the required specifications. In any engineering of electronics, you will encounter trade-offs in your design. Since this is a class A amplifier, it would not be the chosen design for a high-power amplifier application due to thermal power supply considerations. This means that class A amplifiers are inefficient, but result in the best output sound of all the amplifier classes and are commonly used in high fidelity audio amplifier design. One modification we could make to our amplifier would be to go to a class-AB amplifier. This would allow for better efficiency and less over-heating.

Collector Current	**Data Sheet Rating (mA)**	**Simulated Quiescent Value (mA)**	**Simulated Maximum Transient Value (mA)**
Q1	200	8.60	11.3
Q2	-200	-36.6	-49.8
Q3	200	62.8	139

Table 2. Absolute maximum transistor ratings for final design of audio amplifier

	Symbol	**Requirement**	**Sim. Value**	**Unit**
Quiescent Power Supply Current	I_q	≤ 200	-124	mA
Small-Signal Voltage Gain Deviation	GD	≤ 0.1	.00816	dB
1-dB Output Compress ion Point	V^2_{1dB}	≥ 56.8	59.8	dBmV RMS

Table 3. Performance figures-of-merit (output parameters) for final design of audio amplifier

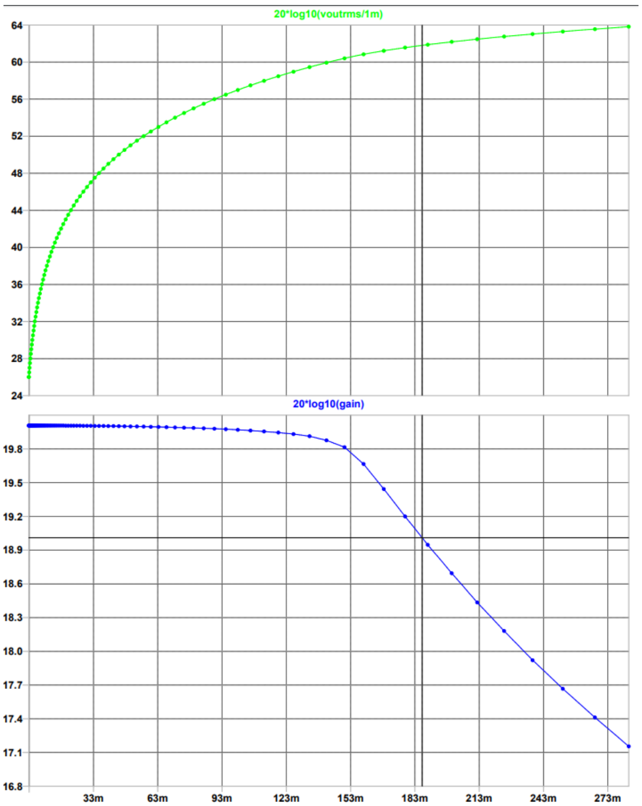

Figure 7. Gain vs Signal(mV)

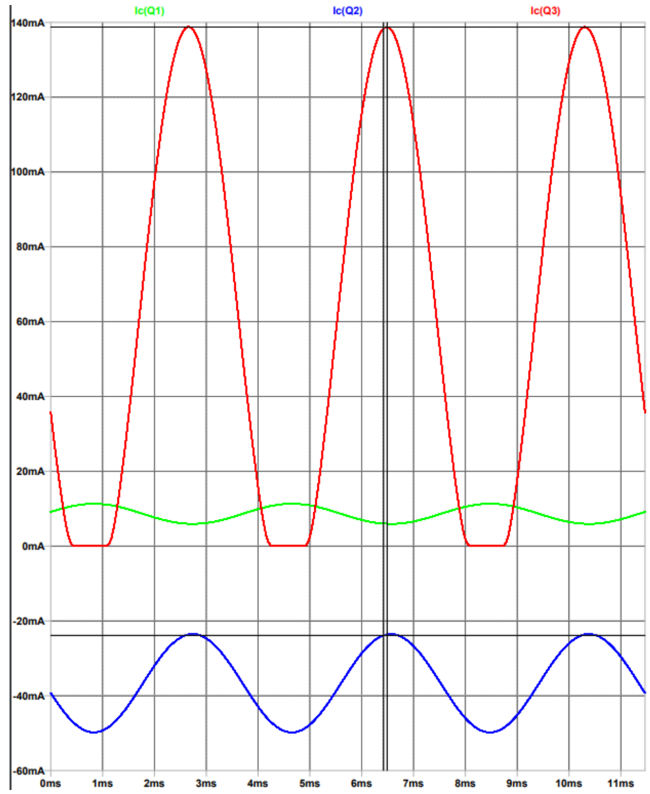

Figure 9. Collector Currents with 1dB Signal

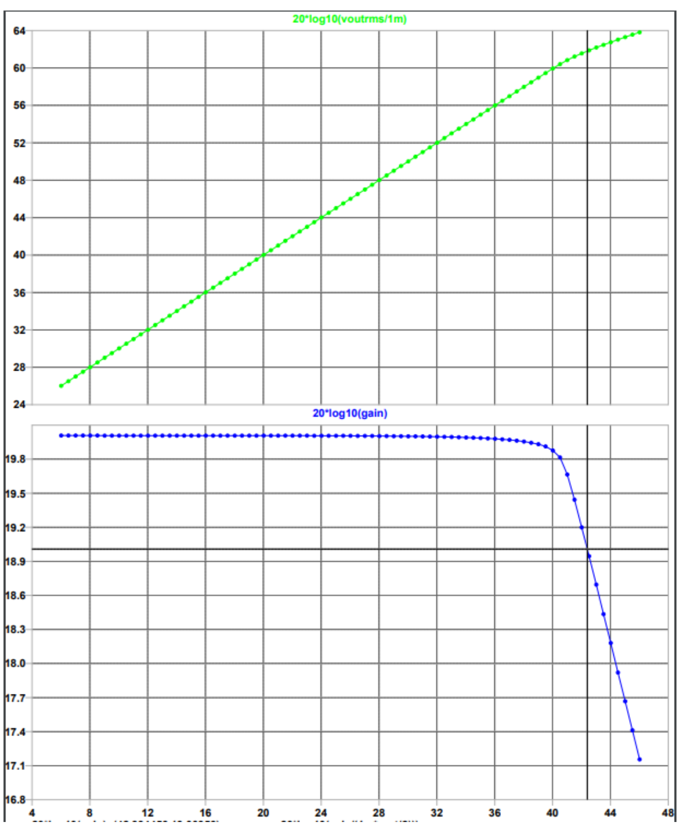

Figure 8. Gain vs Signal (dBmV RMS)

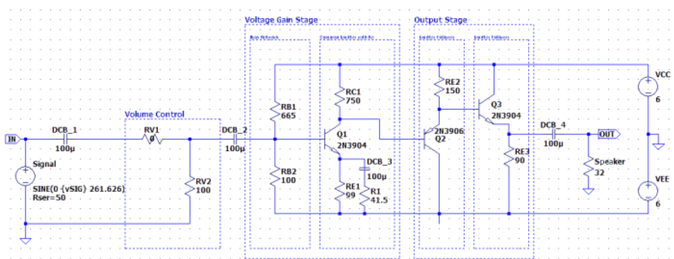

Figure 10. Finalized Audio Amplifier Circuit

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