AUDIO AMPLIFIER

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1 List of Abbreviation and Symbols

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ABSTRACT

Electronic Circuit is an essential subject for every Electronics and Telecommunications Engineering student. This subject covers a huge amount of knowledge about electronic devices and circuit theory, help students to profoundly understand the fountain of the related concepts, also how to apply them to the real life. Accordingly, to have a general look of what we have learned, I try to do a project about making *An Audio Amplifier*.

Within four parts, this report covers the entire process I have followed to accomplish my final product. In the first part ***Introduction***, I will describe in details the specification of my amplifier, also its internal structure and features. The second part ***Calculation and Simulation*** will reveal the way how I got the specific values for each individual parameters, also the schematic design of my circuit through each stage, then cover up by the simulation. To manufacture the product, I have to make its PCB Design, and this step will be introduced in ***Part III: PCB Design***. The last part ***Making Product and Testing*** will finish the whole procedure by comparing the practical measured parameters with the theoretical calculated ones.

Throughout this project, I have found my happiness of the first productive circuit I have ever made. Thanks to it, I also understand more about what you have taught us. Anyway, due to the first time I make a multi-stage circuit myself, my product maybe not the well-being one, even sometimes I stuck in difficulties. Nevertheless, it is very kind of you that you are always ready to help me overcome those drawbacks and accomplish my achievement.

Sincerely,
Long.

Part I
Introduction

2 Description

- An audio amplifier is a device or a system that helps to amplify audio signals with low-power source such as output signal from smart phone's audio jack. The application of audio amplifiers can be seen everywhere, mostly in loudspeaker or music system in house club, movie theater, etc.

- The audio amplifier receives a very small input signal, normally measured as mili-watts (mW) and amplifies each individual parameter of the original signal through multi-stages. At the output, the obtained power is much higher than the pure one (about some watts), depends on the properties of the output speaker(s).

- Those parameters that will be modified (particularly amplified) are usually amplitude (Voltage), strength (Current), or power. In some complex system, also frequency could be change to shift the tone's height (deeper within lower frequency and vice versa). However, in the restriction of this project, my device only works with amplitude, intensity and power.

3 Requirement

3.1 Functional Requirement

- Able to amplify the audio signal.
- Minimize the effects of noise, signal distortion.
- Compatible with variety of common sources.
- Working properly with 12V DC-supplier.

3.2 Non-Functional Requirement

- Easy to use, repair and customize.
- Low price.
- Small and portable.

4 Specification

4.1 Input parameters

- Supplier: 12V-DC.
- Input audio signal:

  Voltage(RMS): 10-100mV-AC.

  Frequency: 1.5kHz.

4.2 Output parameters (Speaker)

- Resistance: 4Ω.
- Power: 3W.
- Voltage amplification factor: 32.

4.3 Choosing Devices

In this circuit, I use 6 transistors, including 3 power transistors. The transistor for amplitude amplifying purpose named ***BC547B***, which is a very common NPN transistor type could be found in every electronic device store. BC548 one is also good, but I do not choose it due to its lower cut-off voltage, compared to the previous one. For the power transistors, ***TIP41C*** and ***TIP42C*** are good choices, where TIP41C is NPN transistor type, TIP42C is PNP one.

All the installed capacitors are biased capacitors, which ranged from 150µF to 1mF, are used for restricting the DC current.

5 Block Diagram

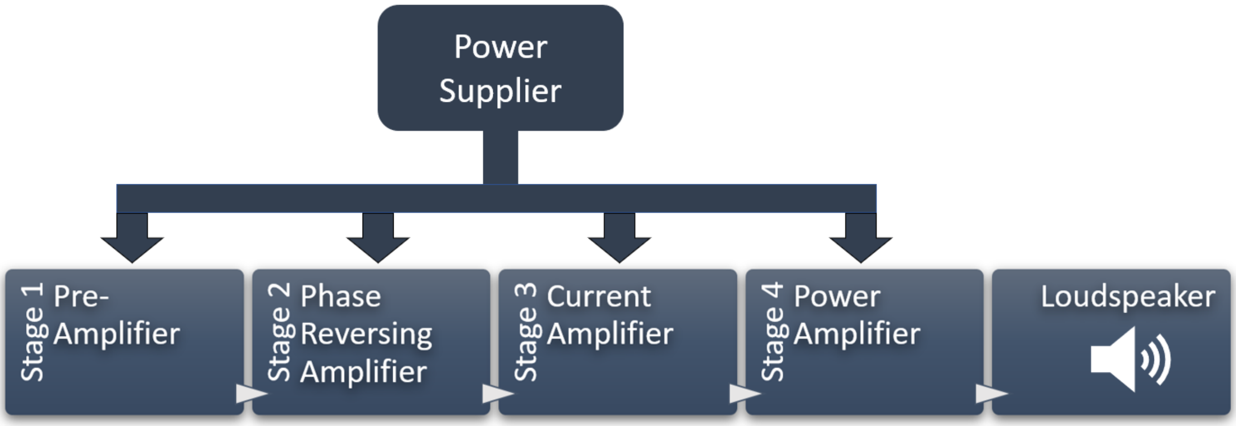

Figure 1: System Block Diagram

Part II
Calculation and Simulation

6 Calculation

For the suitable design purpose, I choose the voltage divider configuration for the first two stages, the next stage will base on the Emitter Follower Darlington connection, and the last will be applied the AB class power amplifier configuration.

Accordingly, the first two configurations have large voltage amplification coefficient, meanwhile the remained ones have the voltage amplification factor approximate one.

Following the requirement, the system has the input voltage from $10mV$ to $100mV$, while the output speaker has the resistance of 4Ω and power of $3W$. Consequently, I obtain the maximum amplitude amplification factor so that the system works properly:

First, I calculate the maximum required AC output voltage applied on the speaker:

(1) $$V_{o_{max}} = \sqrt{PR} = \sqrt{(3W) * (4\Omega)} \approx 3.46V$$

Within the input voltage of maximum $100mV$*, I obtain the maximum voltage amplification factor of the entire circuit:*

(2) $$A_{v_{max}} = \frac{Vo_{max}}{Vi_{max}} = \frac{3.46V}{100mV} \approx 34.6$$

Hence we choose the maximum can-reach voltage amplification factor of 34.

As mention above, the general amplification factor almost depends on the first two stages, while the remained ones do not affect too much. Therefore, I take an equal distribution of amplification factor for the first two stages. The two stages have exactly the same configuration, each one has the amplification factor of $\boxed{A_v \approx \sqrt{32} \approx 5.66}$.

To make sure that the entire circuit works properly throughout all the stages, I choose the voltage difference between the emitter and collector (denoted as V_{CE}) of every transistor equals to six volts ($V_{CE} = 6V$), which is a half of the power supplier's voltage. At this point, I ensure that the range of AC signal's amplitude that the signal is transmitted without distortion reaches the maximum value.

6.1 Stage 1: Pre-Amplifier

Choosing the Q-Point

Base on BC547B's datasheet, I choose the working point of this transistor:

- CE-voltage difference: $V_{CEQ1} = 6V$.
- Base current: $I_{BQ1} = 50\mu A$.
- Collector current: $I_{CQ1} = 12\text{m}A$.
- Amplification Factor: $\beta = \frac{I_{CQ1}}{I_{BQ1}} = 240$.

Calculating

DC-mode parameters

- Calculate Emitter Resistance R_{EQ1} Emitter Current: $I_{EQ1} = \frac{\beta+1}{\beta} \times I_{CQ1} = \frac{240+1}{241} \times 12\text{m}A \approx 12\text{m}A$

  Choosing $V_{EQ1} = \frac{V_{CC}}{10} = 1.2V \Leftrightarrow R_4 + R_5 = R_{EQ1} = \frac{V_{EQ1}}{I_{EQ1}} = \frac{1.2V}{12\text{m}A} = 100\Omega$

  $\boxed{R_4 + R_5 = R_{EQ1} = 100\Omega}$

- Calculate Collector Resistance R_{CQ1}

  Apply KVL:

  $V_{CC} = V_{CQ1} + V_{CEQ1} + V_{EQ1} \Leftrightarrow V_{CQ1} = V_{CC} - V_{CEQ1} - V_{EQ1} \Leftrightarrow V_{CQ1} = 12V - 6V - 1.2V = 4.8V$

  $\Leftrightarrow R_3 = \frac{V_{CQ1}}{I_{CQ1}} = \frac{4.8V}{12mA} = 400\Omega$

  $\boxed{R_3 = 400\Omega}$

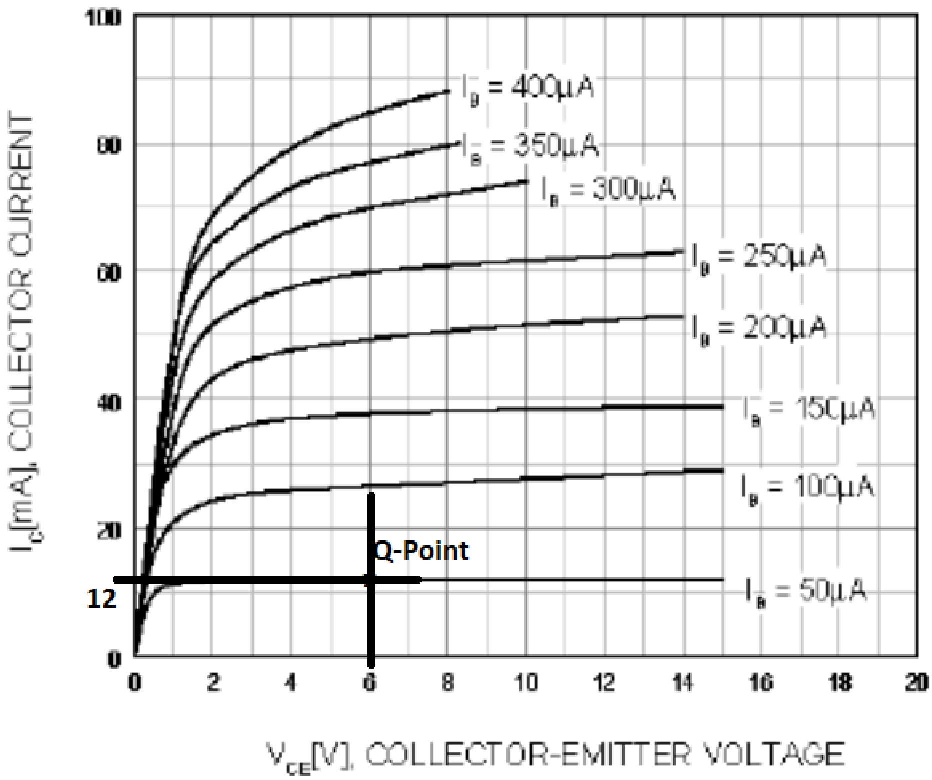

Figure 2: BC547B's Characteristic Line

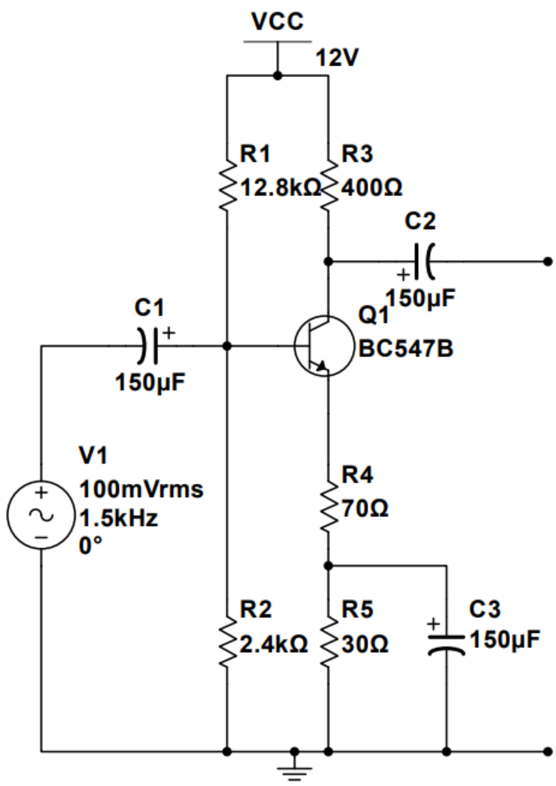

Figure 3: Stage 1: Pre-Amplifier

- Determine R_4 and R_5

  As mentioned above: Stage 1 has the voltage amplification factor: $A_{v1} \approx 5.66$.

  From the ***AC-mode parameters*** section, we obtain the value of r_e: $r_e = 2.17\Omega$

  The voltage amplification factor can be determined via the following formula:

  $A_{v1} = -\frac{\beta_1 R_3}{\beta_1 (r_e + R_4)} = -\frac{R_3}{(r_e + R_4)}$

  $\Leftrightarrow R_4 = \frac{R_3}{|A_{v1}|} - r_e = \frac{400\Omega}{5.66} - 2.17\Omega = 68.5\Omega$

  Choose $R_4 = 70\Omega$,

  so that the voltage amplification factor is $\boxed{A_{v1} = -5.54}$.

  From the above section: $R_4 + R_5 = R_{EQ1} = 100\Omega$

  $\Leftrightarrow \boxed{R_4 = 70\Omega, R_5 = 30\Omega}$.

- Determine R_1 and R_2

  For stability, choose R_2 so that: $10R_2 \leq \beta R_{EQ1} \Leftrightarrow R_2 \leq \frac{240 \times 100\Omega}{10} = 2.4k\Omega$

  Choose $\boxed{R_2 = 2.4k\Omega}$

  Denote: $E_{TH} = \frac{R_2}{R1+R2} V_{CC}$, $R_{TH} = R_1 \parallel R_2 = \frac{R_1 R_2}{R_1 + R_2}$

  Apply KVL: $I_{BQ1} R_{TH} + I_{EQ1} R_{EQ1} = E_{TH} - V_{BEQ1}$

  $\Leftrightarrow \boxed{R_1 = 12.8k\Omega}$

AC-mode parameter

- r_e model resistance: $r_e \approx \frac{26mV}{I_{CQ1}} = 2.17\Omega$
- Input Impedance: $Z_{i1} = R1 \parallel R2 \parallel \beta_{Q1} r_e \Leftrightarrow \boxed{Z_{i1} = 414.1\Omega}$.
- Output Impedance: $\boxed{Z_{o1} = R_3 \parallel R_4 = 59.5\Omega}$

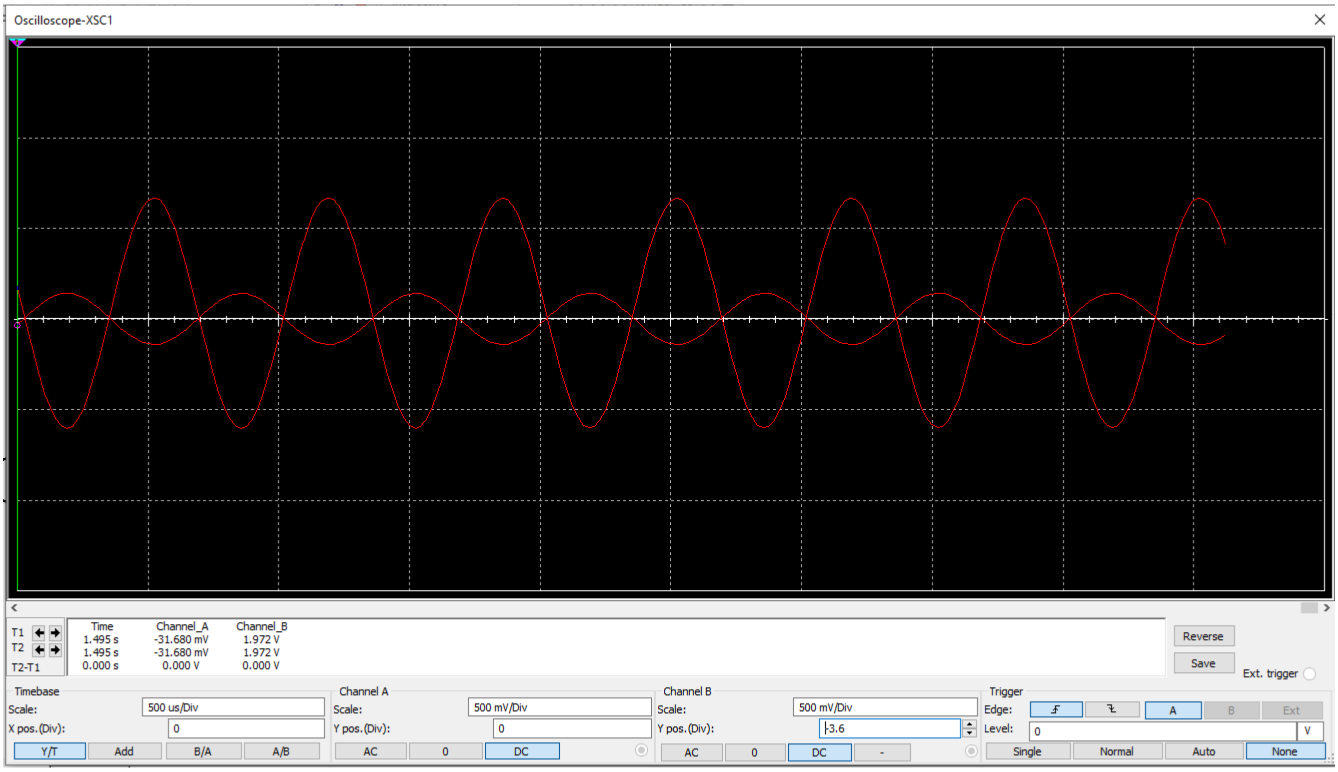

Figure 4: Signal over Stage 1: Phase was inverse

6.2 Stage 2: Phase Reversing Amplifier

Stage 2 has the same parameters with the Stage 1.

The main purpose of this stage is reversing the signal phase, so that it remains the same phase with the original signal after being inverse after the first stage.

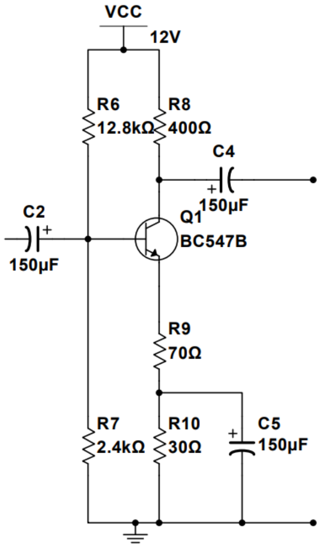

Figure 5: Stage 2: Phase Reversing Amplifier

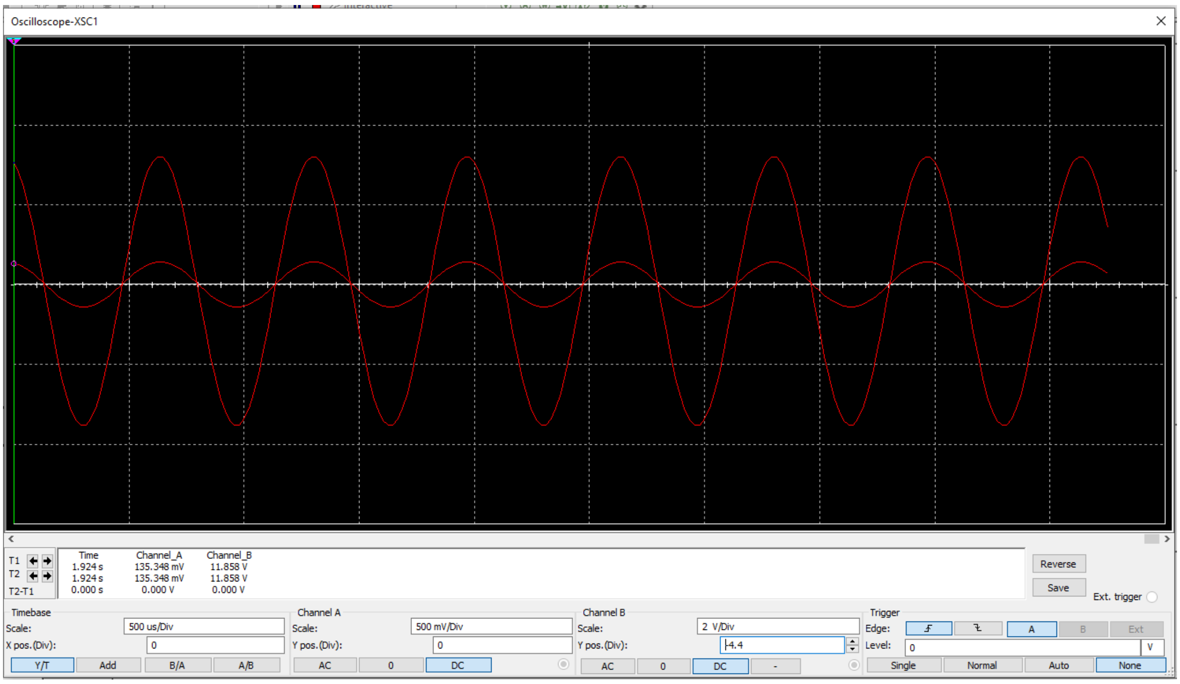

Figure 6: Signal over Stage 2: Phase reversed

6.3 Stage 3: Current Amplifier

Choosing the Q-Point

The amplification factor of transistor Q2 is the same as the two previous ones: $\beta_3 = 240$.
Base on TIP41C's datasheet, I choose the working point of transistor Q4 at 25°C:

- CE-voltage difference: $V_{CEQ4} = 6V$.
- Collector current: $I_{CQ4} = 0.5A$. item Amplification Factor: $\beta = 54$.
- Base current: $I_{BQ4} = \frac{I_{CQ4}}{\beta_4} \approx 9.3mA$.

In the below figure, $V_{CE} = 4V$, but within the low level of I_C, when V_{CE} changes a little bit, the gain hardly changes.

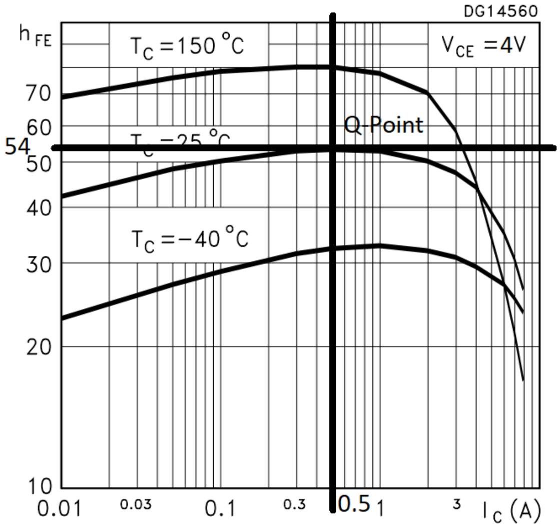

Figure 7: Q4's working point

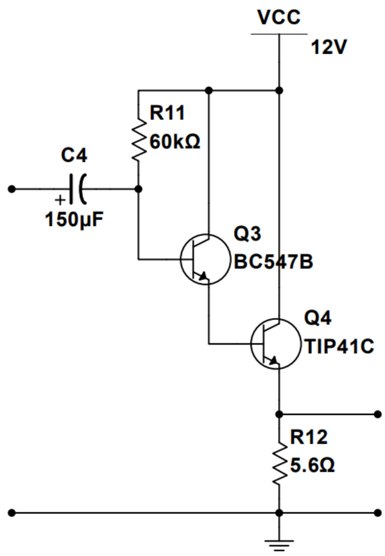

Figure 8: Stage 3: Current Amplifier

DC-mode parameters

- Determine R_{12}

  Emitter Current of Transistor Q4: $I_{EQ4} = \frac{\beta+1}{\beta} \times I_{CQ4} = \frac{54+1}{54} \times 0.5A = 0.5926A$

  $\Leftrightarrow R_{12} = R_{EQ4} = \frac{V_{EQ4}}{I_{EQ4}} = \frac{6V}{0.5926A} \approx 11.8\Omega$

  Choose $\boxed{R_{12} = 12\Omega}$

- Determine R_{11}

  Emitter Current of Q3: $I_{EQ3} = I_{BQ4} = 9.3mA$

  Base Current of Q3: $I_{BQ3} = \frac{I_{EQ3}}{\beta_3+1} = \frac{9.3mA}{240+1} \approx 38.59\mu A$.

  Apply KVL:

  $V_{CC} - I_{BQ3}R_{11} - V_{BEQ3} - V_{BEQ4} - V_{EQ4} = 0 \Leftrightarrow R_{11} = \frac{12V-0.7V-0.7V-6V}{38.59\mu A} \approx 120k\Omega$

  Choose $\boxed{R_{11} = 120k\Omega}$

AC-mode parameter

- r_e model resistance: $r_e \approx \frac{26mV}{I_{EQ4}} = \frac{26mV}{0.5926A} \approx 43.87m\Omega$

- Input Impedance: $Z_{i3} = R_{BQ3} \parallel \beta_{Q3}\beta_{Q4}R_{EQ4} \Leftrightarrow Z_{i3} = R_{11} \parallel \beta_{Q3}\beta_{Q4}R_{12} \Leftrightarrow \boxed{Z_{i3} = 31609.8\Omega}$.

- Output Impedance: $\boxed{Z_{o3} \approx r_e = 25.53m\Omega}$

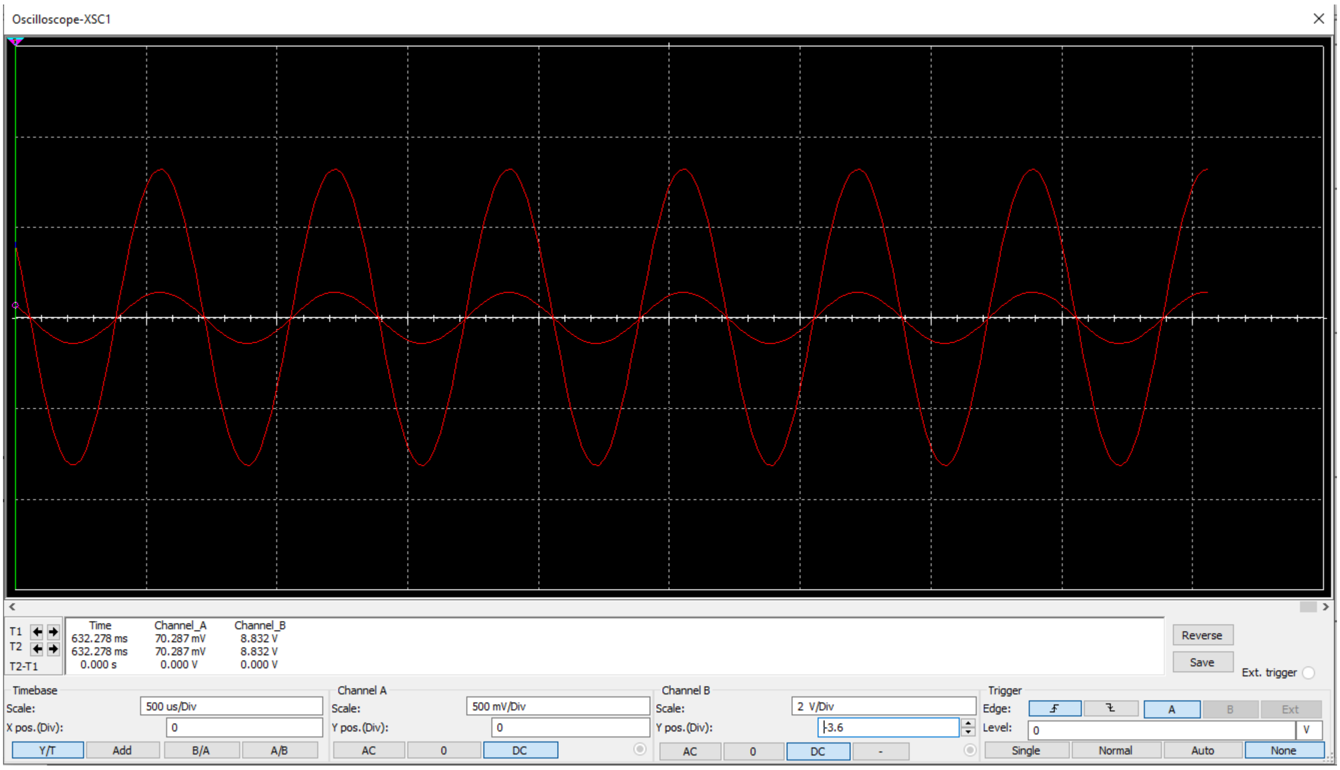

Figure 9: Signal at the output terminal of Stage 3

6.4 Stage 4: Power Amplifier

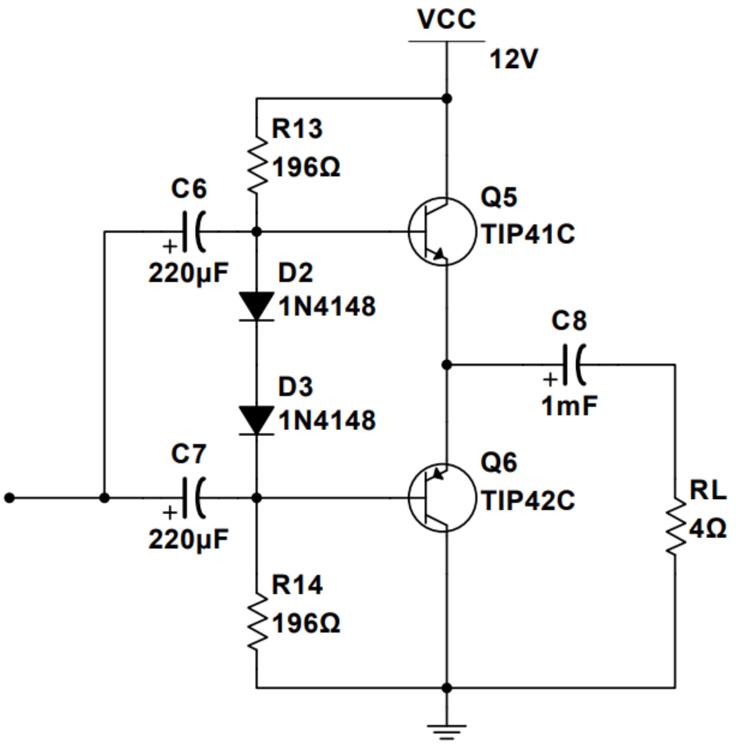

Figure 10: Stage 4: Power Amplifier

Choosing the Q-Point

In this stage, both two transistors TIP41C and TIP42C has the amplification factor $\beta_{Q5} = \beta_{Q6} = 54$ (equal to β_{Q4}) in the above analysis.

DC-mode parameters

As mention above, for working properly: $V_{CEQ5} = V_{CEQ6} = 6V$

The two diodes are connected between two base-terminal of the corresponding transistors Q5 and Q6 help to bias the two transistors, so that the two transistors turn into working condition (B-E biased)

The speaker has resistance $R_L = 4\Omega$

⇔ The maximum current through the speaker: $I_L = \frac{6V}{4\Omega} = 1.5A$

⇔ The emitter current of the transistor Q6:$I_{EQ6} = I_{EQ6} = I_L = 1.5A$

⇔ The base current of Q6: $I_{BQ6} = \frac{I_{EQ6}}{\beta_{Q6}+1} = \frac{1.5A}{54+1} \approx 27.3mA$

Apply KVL:

$I_{BQ6}R_{14} = V_{CEQ6} - V_{BEQ6} = 6V - 0.7V = 5.3V \Leftrightarrow R_{14} = \frac{5.3V}{27.3mA} \approx 194.3\Omega$

Choose $\boxed{R_{13} = R_{14} = 196\Omega}$

AC-mode parameters

- r_e model resistance: $r_e \approx \frac{26mV}{I_L} = \frac{26mV}{1.5A} \approx 17.3m\Omega$
- Input Impedance: $Z_{i4} = R_{13} \parallel \beta_{Q6}R_L \Leftrightarrow \boxed{Z_{i4} = 102.8\Omega}$.
- Output Impedance: $\boxed{Z_{o4} = r_e \parallel R_L = 17.2m\Omega}$

6.5 Amplification Factor

- Stage 1: $A_{vL1} = -5.54,\ Z_{i1} = 414.1\Omega,\ Z_{o1} = 59.5\Omega$
- Stage 2: $A_{vL2} = -5.54,\ Z_{i2} = 414.1\Omega,\ Z_{o2} = 59.5\Omega$
- Stage 3: $A_{vL3} \approx 1,\ Z_{i3} = 31609.8\Omega,\ Z_{o3} = 25.53m\Omega$
- Stage 4: $A_{vL4} \approx 1,\ Z_{i4} = 102.8\Omega,\ Z_{o4} = 17.2m\Omega$

$\Leftrightarrow$ The amplification factor of the system: $A_V = (A_{vL1}) \times (A_{vL2}\frac{Z_{i2}}{Z_{i2}+Z_{o1}}) \times (A_{vL3}\frac{Z_{i3}}{Z_{i3}+Z_{o2}}) \times (A_{vL4}\frac{Z_{i4}}{Z_{i4}+Z_{o3}})$
$\Leftrightarrow$ $\boxed{A_V = 27}$.
The current amplification factor of the system: $A_I = \frac{Z_{i1}}{R_L} \times A_V \approx 2795$.
(Denote the direction of output current is down to ground throughout the load).

7 Simulation

7.1 Schematic

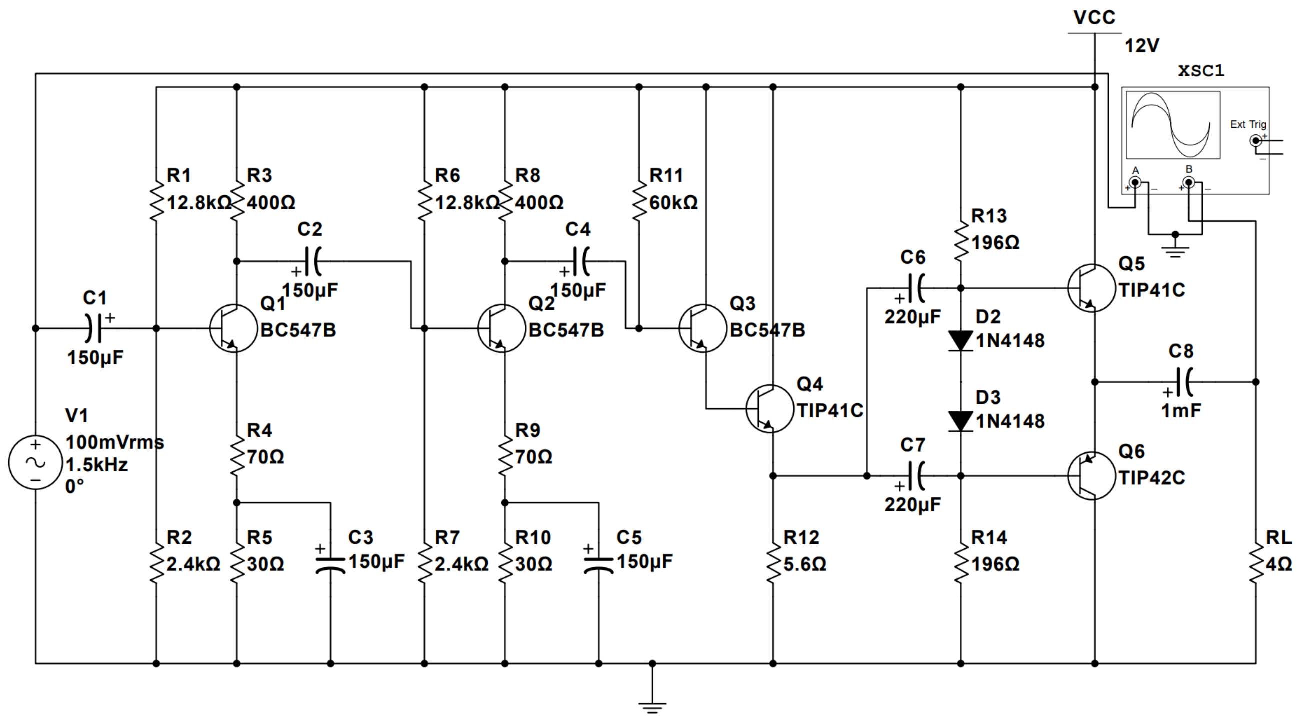

Figure 11: The Entire Schematic Diagram

7.2 Signal Results

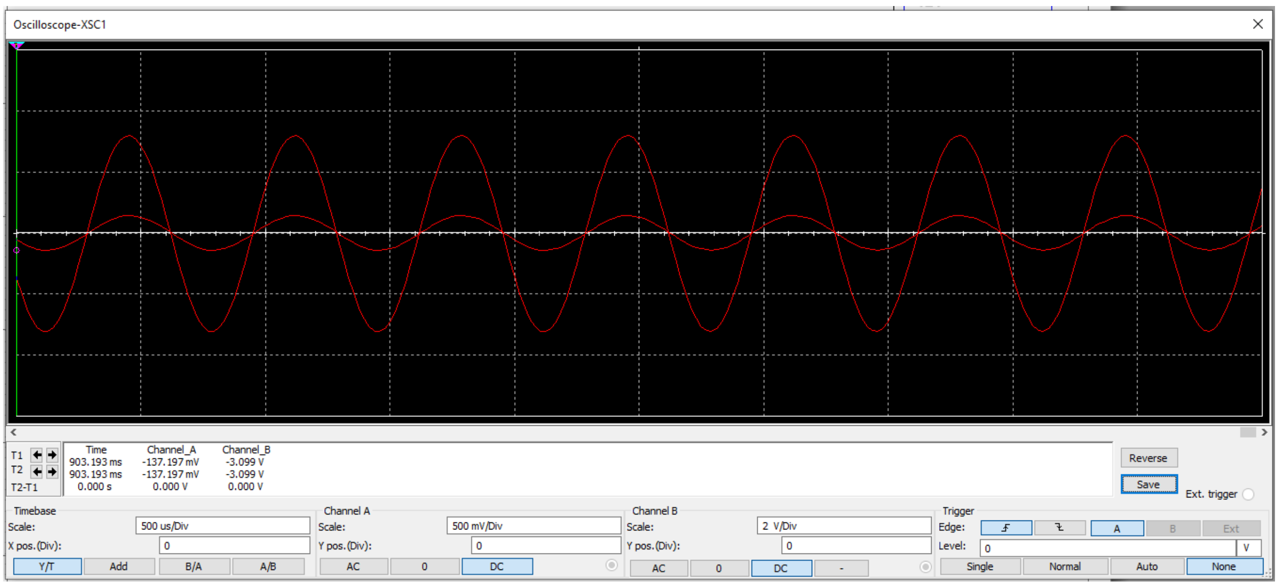

Figure 12: Signal Simulation on ***MultiSim***

Part III
PCB Design

7.3 Schematic for exporting to PCB Design

Replace some suitable components (Also available resistors on the market) for PCB designing purpose:

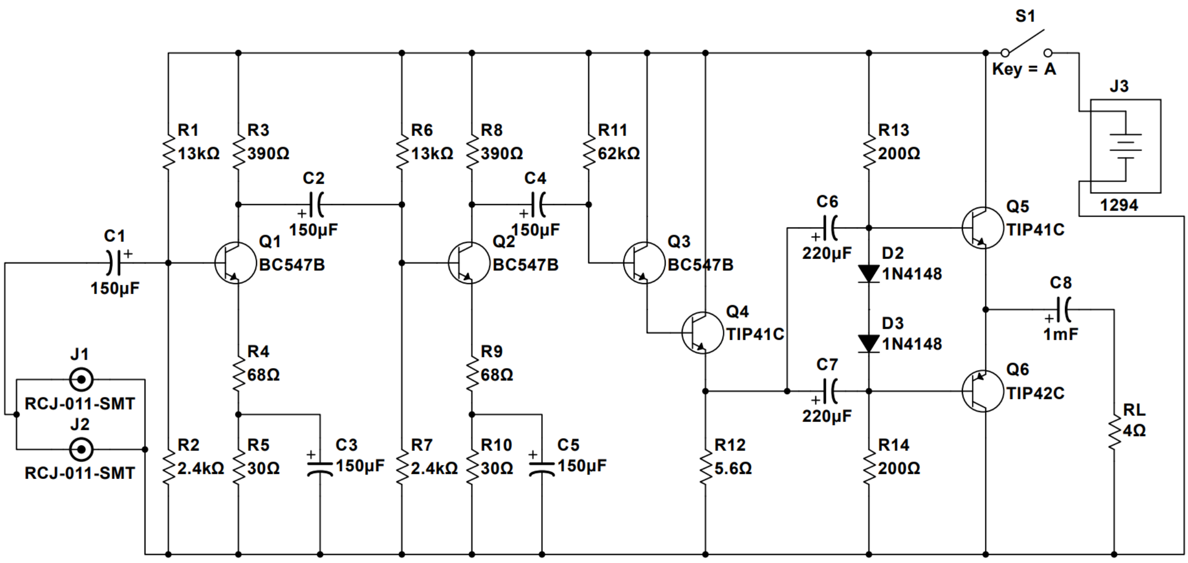

Figure 13: Schematic for exporting to PCB

7.4 Product Preview

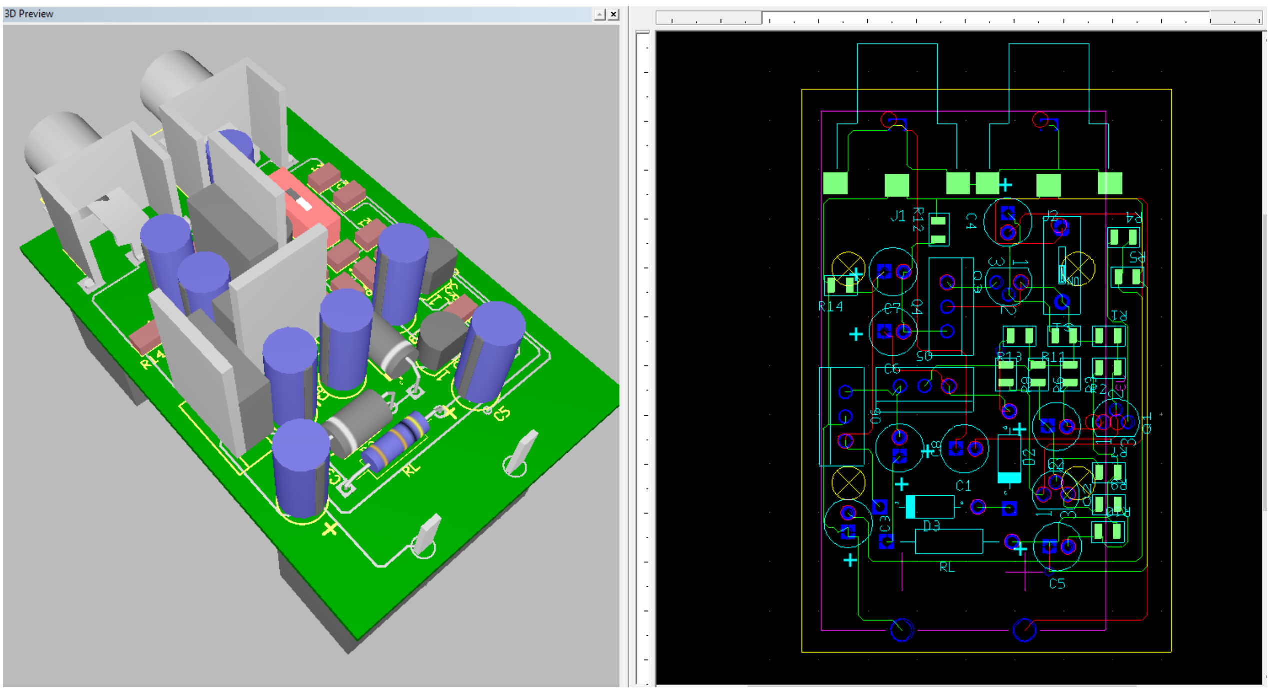

Figure 14: PCB Design: 3D and 2D view

Part IV
Making Product and Testing

8 Testing with Breadboard

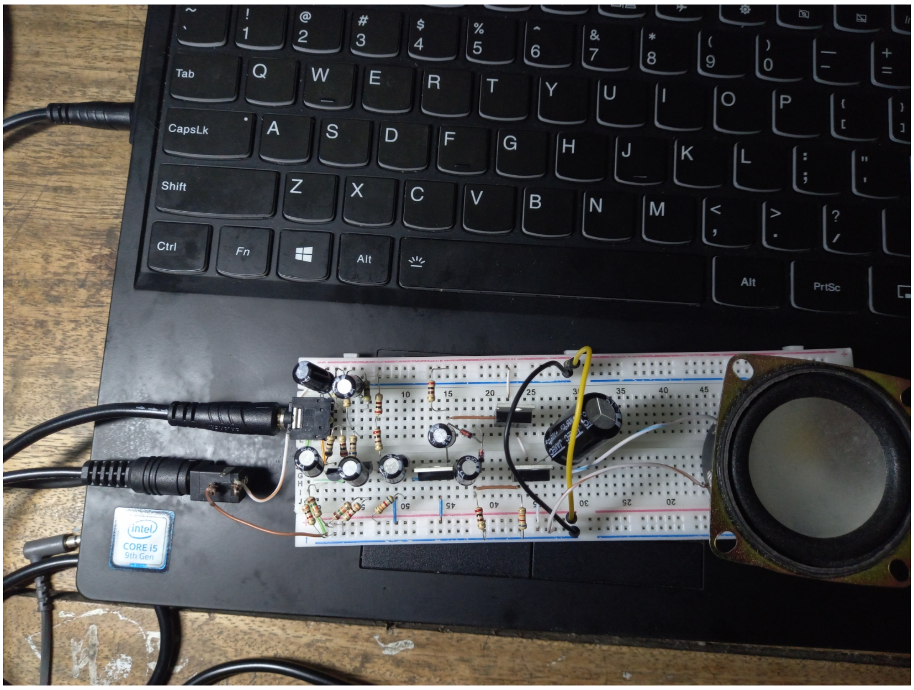

Figure 15: Breadboard Testing

Part V
Conclusion

Reference