HANOI UNIVERSITY OF SCIENCE AND TECHNOLOGY
SCHOOL OF ELECTRONICS AND TELECOMMUNICATION

FINAL PROJECT
ELECTRONIC CIRCUIT I

Topic:

AUDIO AMPLIFIER

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Hanoi, August 31, 2021

AUDIO AMPLIFIER

Hoang-Long.Vu

August 31, 2021

List of Abbreviation and Symbols

- **KVL**: Kirchhoff's Voltage Law
- **KCL**: Kirchhoff's Current Law
- **AC**: Alternating Current
- **DC**: Direct Current
- **P**: Power
- **V**: Voltage
- **I**: Current
- **R**: Resistance
- **C**: Capacitance
- **f**: Frequency
- β: gain coefficient
- **Z**: Impedance
- **RMS**: Root Mean Square
- **p-p** peak-to-peak

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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 five 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

1 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.

2 Requirement

2.1 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.

2.2 Non-Functional Requirement

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

3 Specification

3.1 Input parameters

- Supplier: 12V-DC.

- Input audio signal:

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

  Frequency: 16Hz-20kHz.

3.2 Output parameters (Speaker)

- Resistance: 4Ω.
- Power: 3W.
- Voltage amplification factor: 45.

3.3 Choosing Devices

In this circuit, I use 5 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 220µF to 2.2mF (depending on the formula $C = \frac{1}{2\pi f Z_c}$, where $f \approx 16Hz$ - *the minimum listening level of humans* $Z_C = Z_{i/o}$), are used for restricting the DC current.

4 Block Diagram

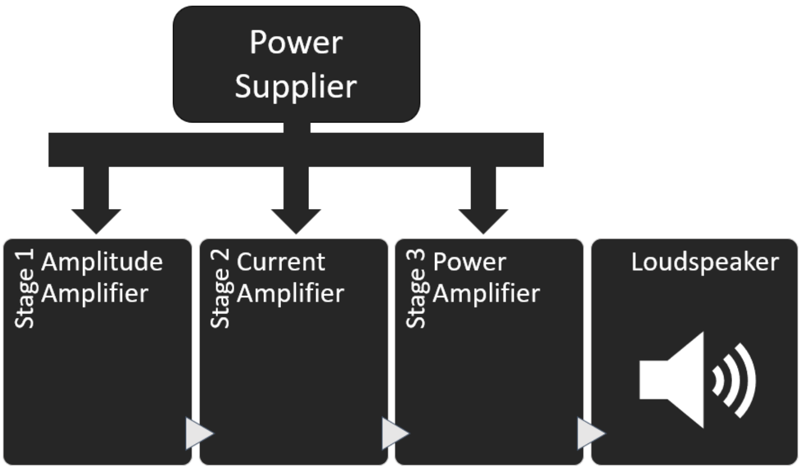

Figure 1: System Block Diagram

Part II
Calculation and Simulation

5 Calculation

For the suitable design purpose, I choose the voltage divider configuration for the first stage, 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 configuration 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 can-be-reached AC output voltage applied on the speaker:

(1) $$V_{o_{max}}(p) = \sqrt{2PR} = \sqrt{2(3W)(4\Omega)} \approx 4.9V$$

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

(2) $$A_{v_{max}} = \frac{Vo_{max}}{Vi_{max}} = \frac{4.9V}{100mV} \approx 49$$

Hence we choose the maximum can-be-reached voltage amplification factor of 49.

Anyway, for safe working purpose, I choose the gain of the first stage of slightly less than the absolution of -45 (by round up the bias resistance in the below calculation, negative sign due to the specification of voltage divider configuration, that cause the phase reverse of the signal but not affects the sound's quality), while the other ones have the gain approximate one, so that the entire absolute gain of the system close to 45 as requirement.

For whom want to know why I choose the value $12V$ for the supplier, this value has obtained from the maximum required AC output voltage applied on the speaker as mentioned above:

(3) $$V_{o_{max}}(p-p) = 2\sqrt{2} \times V_{o_{max}}(rms) = 2\sqrt{2} \times 3.46V \approx 9.79V$$

$\Leftrightarrow$ Choose $\boxed{V_{supplier} = 12V}$.

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.

5.1 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: $I_{CQ1} = 12mA$.
- Amplification Factor: $\beta = \frac{I_{CQ1}}{I_{BQ1}} = 240$.

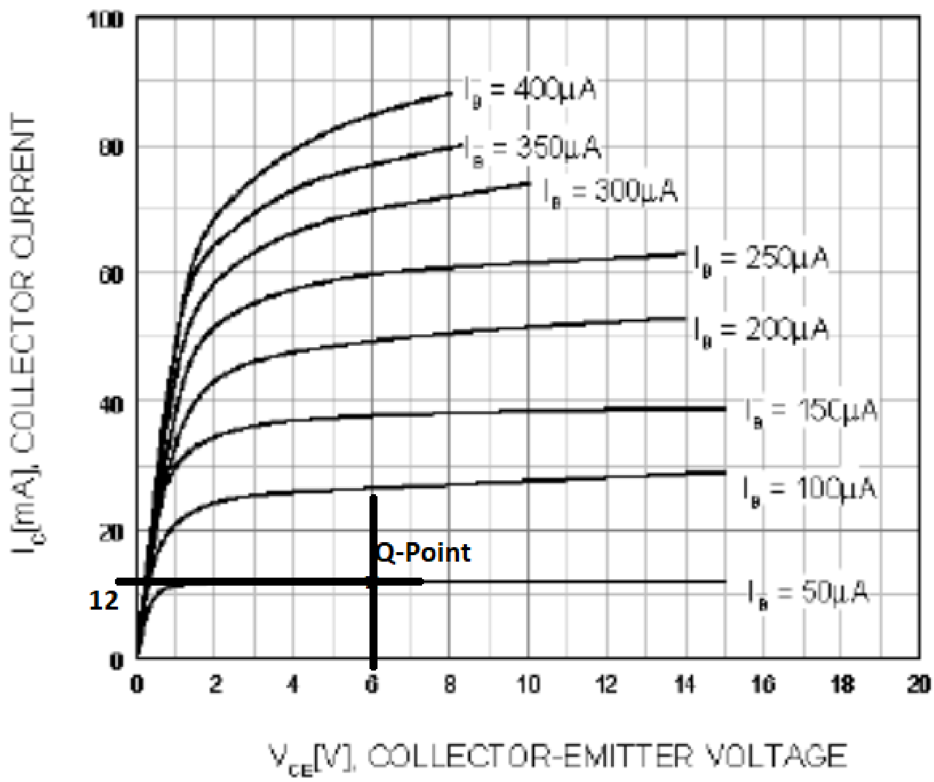

Figure 2: BC547B's Characteristic Line

Calculating

DC-mode parameters

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

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

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

- Calculate Collector Resistance R_{CQ1}

  Apply KVL:

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

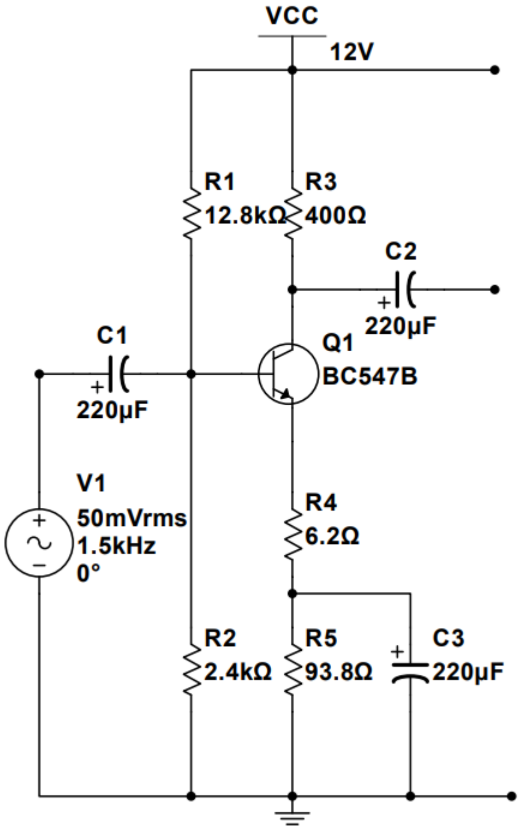

Figure 3: Stage 1: Pre-Amplifier

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

$\boxed{R_3 = 400\Omega}$

- Determine R_4 and R_5

  As mentioned above: Stage 1 has the voltage gain: $A_{v1} \approx -45$.

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

  The voltage gain can be determined via the following formula:

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

  $\Leftrightarrow R_4 = \frac{R_3}{|A_{v1}|} - r_e = \frac{400\Omega}{45} - 2.17\Omega = 6.72\Omega$

  Choose $R_4 = 6.2\Omega$,

  so that the voltage gain is $\boxed{A_{v1} = -47.8}$ (under 49 is still good).

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

  $\Leftrightarrow \boxed{R_4 = 6.2\Omega, R_5 = 93.8\Omega}$.

- Determine R_1 and R_2

  For stability, choose R_2 so that: $10R_2 \leq \beta R_{EQ1} \Leftrightarrow R_2 \leq \frac{240\times100\Omega}{10} = 2.4k\Omega$

  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: $Z_{i1} = R1 \parallel R2 \parallel \beta_{Q1}(r_e + R_4) \Leftrightarrow \boxed{Z_{i1} = 1007.5\Omega}$.
- Output Impedance: $\boxed{Z_{o1} = R_3 \ = 400\Omega}$

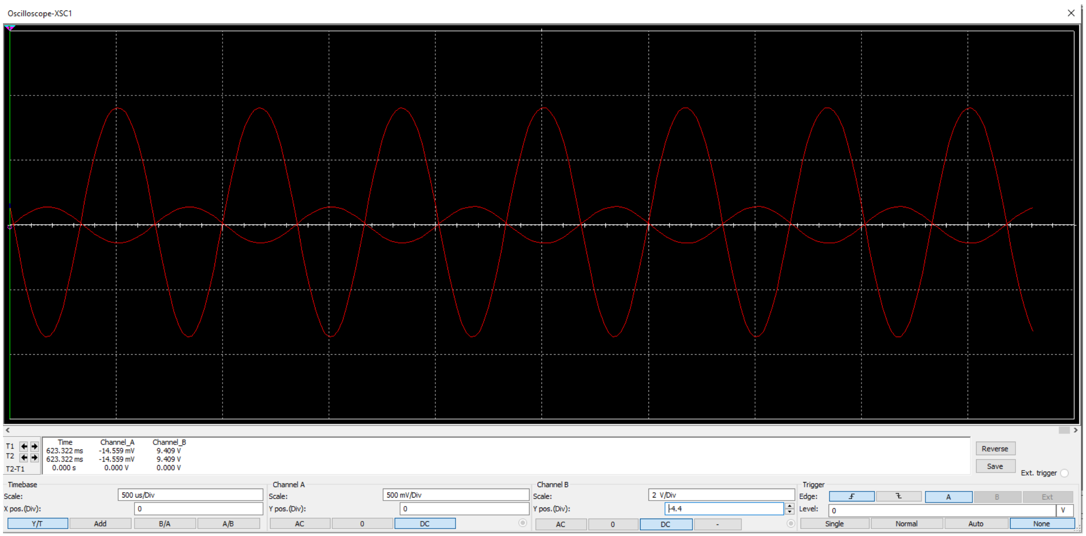

Figure 4: Signal over Stage 1: Phase was inverse, Amplitude was amplified

5.2 Stage 2: Current Amplifier

Choosing the Q-Point

The amplification factor of transistor Q2 is the same as the two previous ones: $\beta_2 = 240$.

Following the TIP41C's data-sheet, at 25°C, the Amplification factor of this transistor is 54, where the collector current is $0.6A$. However, once TIP41C is an power transistor and works with the high current, the heat through it will quickly raise and pull up the amplification factor. In this case, I choose the following arguments for the corresponding parameters:

- CE-voltage difference: $V_{CEQ3} = 6V$.
- Collector current: $I_{CQ3} = 0.6A$.
- Amplification Factor: $\beta_3 = 60$.
- Base current: $I_{BQ3} = \frac{I_{CQ3}}{\beta_3} = 10mA$.

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.

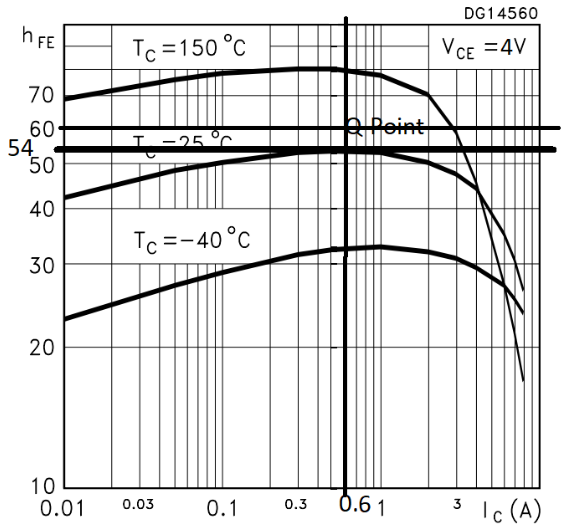

Figure 5: Q3's working point

DC-mode parameters

- Determine R_7

  Emitter Current of Transistor Q3: $I_{EQ3} \approx I_{CQ3} = 0.6A$

  $\Leftrightarrow R_7 = R_{EQ3} = \frac{V_{EQ3}}{I_{EQ3}} = \frac{6V}{0.6A} = 10\Omega$

  Choose $\boxed{R_7 = 10\Omega}$

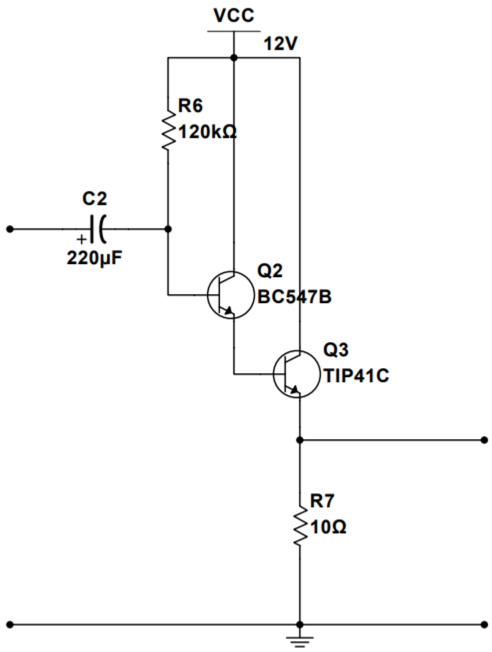

Figure 6: Stage 2: Current Amplifier

- Determine R_6

  Emitter Current of Q2: $I_{EQ2} = I_{BQ3} = 10mA$

  Base Current of Q2: $I_{BQ2} = \frac{I_{EQ2}}{\beta_3+1} = \frac{10mA}{240+1} \approx 41.5\mu A$.

  Apply KVL:

  $V_{CC} - I_{BQ2}R_6 - V_{BEQ2} - V_{BEQ3} - V_{EQ3} = 0 \Leftrightarrow R_6 = \frac{12V-0.7V-0.7V-6V}{41.5\mu A} \approx 110k\Omega$

  When the power transistor is heated, the amplification argument will raised, then I choose $\boxed{R_6 = 120k\Omega}$.

AC-mode parameter

- r_e model resistance: $r_e \approx \frac{26mV}{I_{EQ3}} = \frac{26mV}{0.61A} \approx 42.62m\Omega$

- Input Impedance: $Z_{i2} = R_{BQ2} \parallel \beta_{Q2}\beta_{Q3}(R_{EQ3} \parallel Z_{i3}) \Leftrightarrow Z_{i2} = R_6 \parallel \beta_{Q2}\beta_{Q3}(R_7 \parallel Z_{i3}) \Leftrightarrow \boxed{Z_{i2} \approx 63.55\text{k}\Omega}$.

- Output Impedance: $\boxed{Z_{o3} \approx r_e = 42.62m\Omega}$

- Checking again

  Obtaining from above and below, I have:

  - The current gain of the first stage: $A_{i1} = 0.75$
  - The Input Impedance of Stage 3: $Z_{i3} = 151.5\Omega$
  - The maximum current gain of the last stage: $A_{i3} = A_{v3} \times \frac{Z_{i3}}{R_L} = 37.88$

  $\Leftrightarrow$ The output current of Stage 2: $I_{o2} = I_{i3} = 2 \times \frac{I_L(p)}{A_{i3}} \approx 64mA$

– The input current of Stage 2: $I_{i2} = I_{o1} = I_{i1} \times A_{i1} = A_{i1} \times \frac{V_{in}}{Z_{in}} = 0.75 \times \frac{100mV}{1007.5\Omega} \approx 0.75mA$

Thus the required current gain through Stage 2 is: $A_{i2} = \frac{I_{o2}}{I_{i2}} = 854$

$\Leftrightarrow$ The required input impedance of stage 2: $Z_{i2} = \frac{A_{i2} \times Z_{i3}}{A_{v2}} = \frac{640 \times 151.5\Omega}{1} = 129.3k\Omega$ larger than the above calculated Z_{i2}.

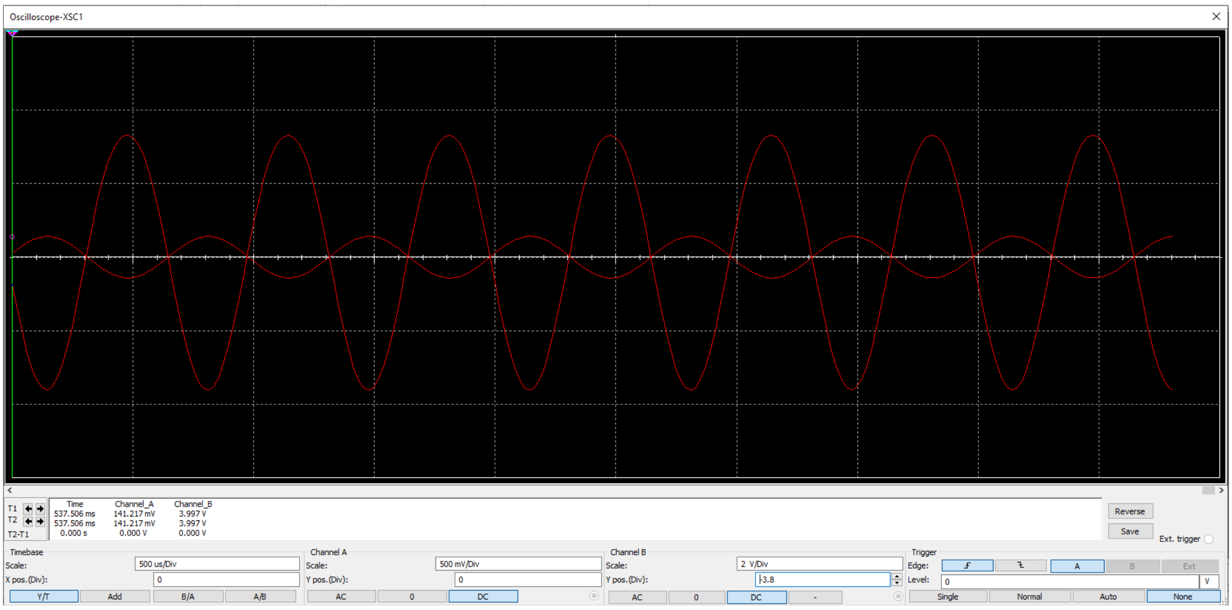

Figure 7: Signal at the output terminal of Stage 2

5.3 Stage 3: Power Amplifier

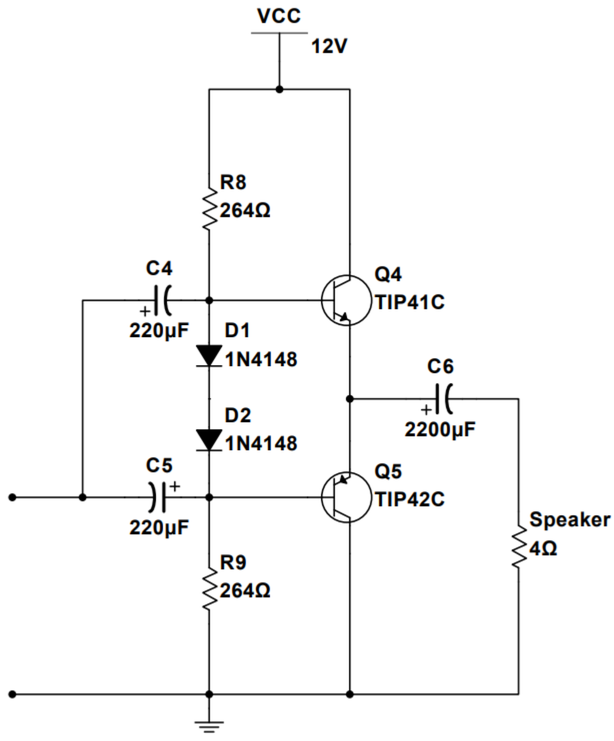

Figure 8: Stage 3: Power Amplifier

Choosing the Q-Point

In this stage, both two transistors TIP41C and TIP42C has the amplification factor $\beta_{Q4} = \beta_{Q5} = 60$ (equal to β_{Q3}) in the above analysis.

Determine Parameters

As mention above, for working properly: $V_{CEQ4} = V_{CEQ5} = 6V$

The two diodes are connected between two base-terminal of the corresponding transistors Q4 and Q5 help to bias the two transistors, so that the two transistors turn into working condition (B-E biased)

The speaker has resistance $R_L = 4\Omega$

$\Leftrightarrow$ The root mean square current through the speaker: $I_L(rms) = \sqrt{\frac{3W}{4\Omega}} \approx 0.87A$

$\Leftrightarrow$ The peak current through the speaker: $I_L(p) = \sqrt{2} * I_L(rms) \approx 1.22A$

The current of the speaker is generated by the difference of two instant values of two emitter currents of transistors Q4 and Q5. It means those two currents have the amplitudes act as two reverse-phase sinusoid waves.

Therefore, the root mean square current of those two currents are:

$I_{EQ4}(p) = I_{EQ5}(p) = I_L(p) = 1.22A$

$\Leftrightarrow$ The base current of Q4: $I_{BQ4} = \frac{I_{EQ4}}{\beta_{Q4}+1} = \frac{1.22A}{60+1} \approx 20mA$

Apply KVL:

$I_{BQ4}R_8 = V_{CC} - V_{BEQ4} - V_{EQ4} = V_{CC} - V_{BEQ4} - (V_{CC} - V_{CEQ4}) = 5.3V \Leftrightarrow R_8 = \frac{5.3V}{20mA} \approx 264\Omega$

Choose $\boxed{R_8 = R_9 = 264\Omega}$

AC Parameters

- r_e model resistance: $r_e \approx \frac{26mV}{I_L} = \frac{26mV}{1.22A} \approx 21.3m\Omega$
- Input Impedance: $Z_{i3} = R_8 \parallel \beta_{Q4}(r_e + R_L) = 151.5\Omega \Leftrightarrow \boxed{Z_{i3} = 151.5\Omega}$.
- Output Impedance: $\boxed{Z_{o3} = R_L \parallel r_e \approx 21.3m\Omega}$

5.4 Gain

- Stage 1: $A_{vL1} = -47.8$, $Z_{i1} = 1007.5\Omega$, $Z_{o1} = 400\Omega$
- Stage 2: $A_{vL2} \approx 1$, $Z_{i2} = 63.55\text{k}\Omega$, $Z_{o2} = 42.62m\Omega$
- Stage 3: $A_{vL3} \approx 1$, $Z_{i3} = 151.5\Omega$, $Z_{o3} = 21.3m\Omega$

The current gain of each stage:

- Stage 3: $A_{i3} = 37.88$ (calculated in the checking section of stage 2 calculation)
- Stage 2: $A_{i2} = A_{v2} \times \frac{Z_{i2}}{Z_{i3}} = 1 \times \frac{63.55k\Omega}{151.5\Omega} = 419.14$
- Stage 1: $A_{i1} = A_{v1} \times \frac{Z_{i1}}{Z_{i2}} = -47 \times \frac{-1007.5\Omega}{63.55k\Omega} = 0.75$

$\Leftrightarrow$ The amplification factor of the system: $A_V = A_{vL1}\frac{Z_{i1}}{Z_{i1}+R_s} \times A_{vL2}\frac{Z_{i2}}{Z_{i2}+Z_{o1}} \times A_{vL3}\frac{Z_{i3}}{Z_{i3}+Z_{o2}} \approx -47$ where $R_s \approx 0$

$\Leftrightarrow \boxed{A_V = -47}$.

The current amplification factor of the system: $A_I = -\frac{Z_{i1}}{R_L} \times A_V \Leftrightarrow \boxed{A_I = 11838}$. *(Denote the direction of output current is down to ground throughout the load).*

5.5 Power

- Stage 1: $P_1 = V_{o1} \times I_{o1} = -V_{i1}A_{v1} \times I_{i1}A_{i1} = 100mV \times 47 \times 0.75mA = 3.525mW$
- Stage 2: $P_2 = V_{o2} \times I_{o2} = -V_{i2}A_{v2} \times I_{i2}A_{i2} = 1 \times V_{o1} \times I_{i3} = 4.7V \times 64mA = 0.3W$
- Output Voltage: $V_o = V_i \times |A_v| = \frac{100mV}{\sqrt{2}} \times 47 = 3.32V$
- Output Current: $I_o = I_i \times |A_i| = \frac{0.1mA}{\sqrt{2}} \times 11838 = 0.84A$

$\Leftrightarrow P_o = V_o \times I_o = 2.78W$ $(R_L = \frac{V_o}{I_o} = 3.95 \approx 4\Omega)$

$\boxed{P_o = 2.78W}$

6 Simulation

6.1 Schematic

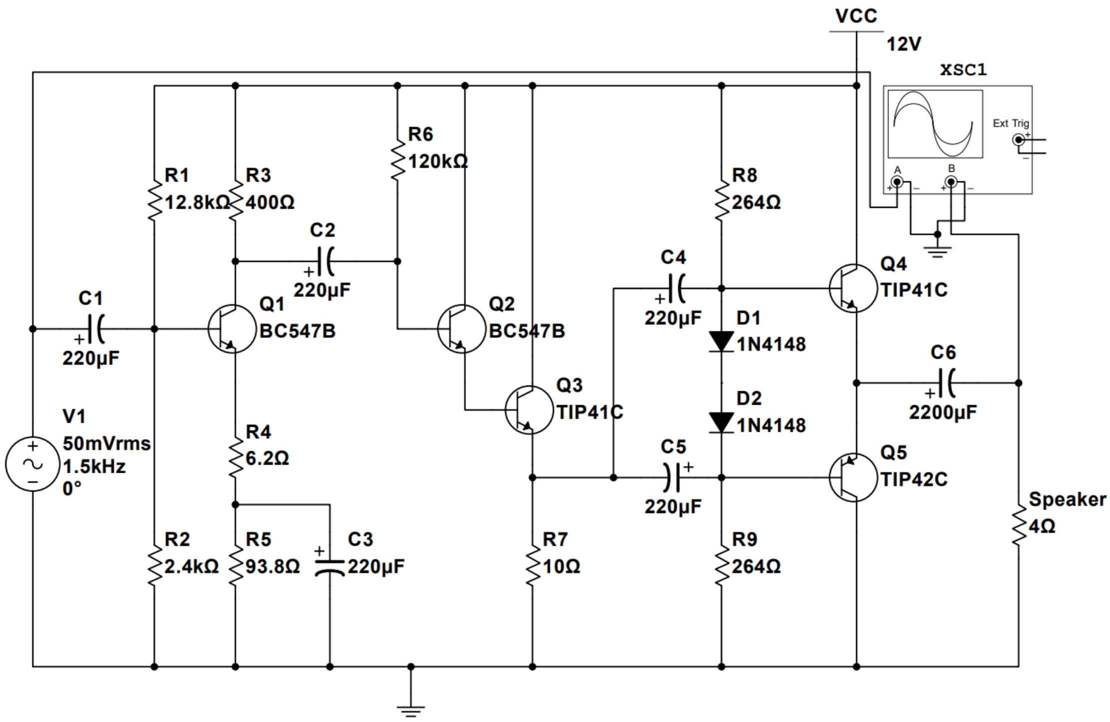

Figure 9: The Entire Schematic Diagram

6.2 Signal Results

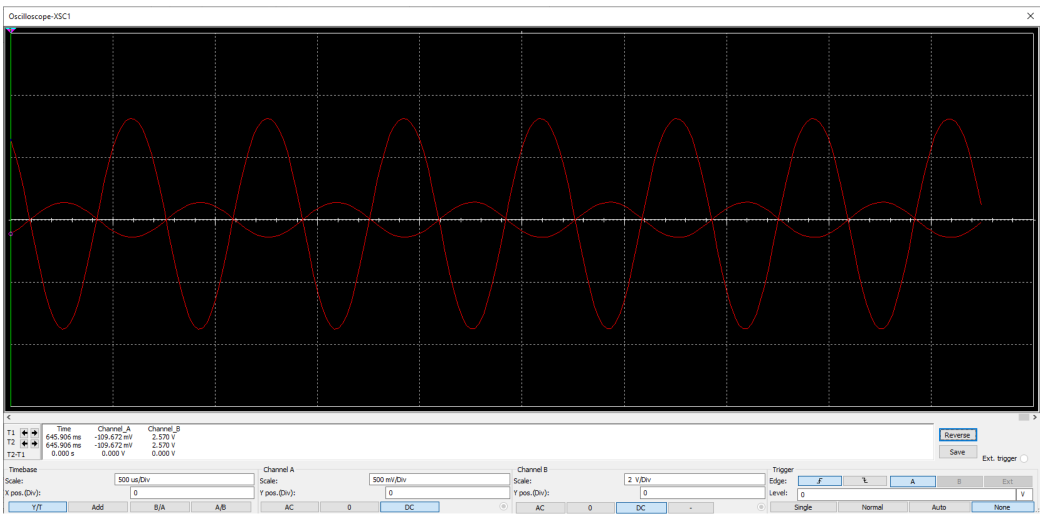

Figure 10: Signal Simulation on ***MultiSim***

Part III

PCB Design

In this design step, I use Software ***Altium Designer*** to derive the PCB layout.

6.3 Schematic for exporting to PCB Design

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

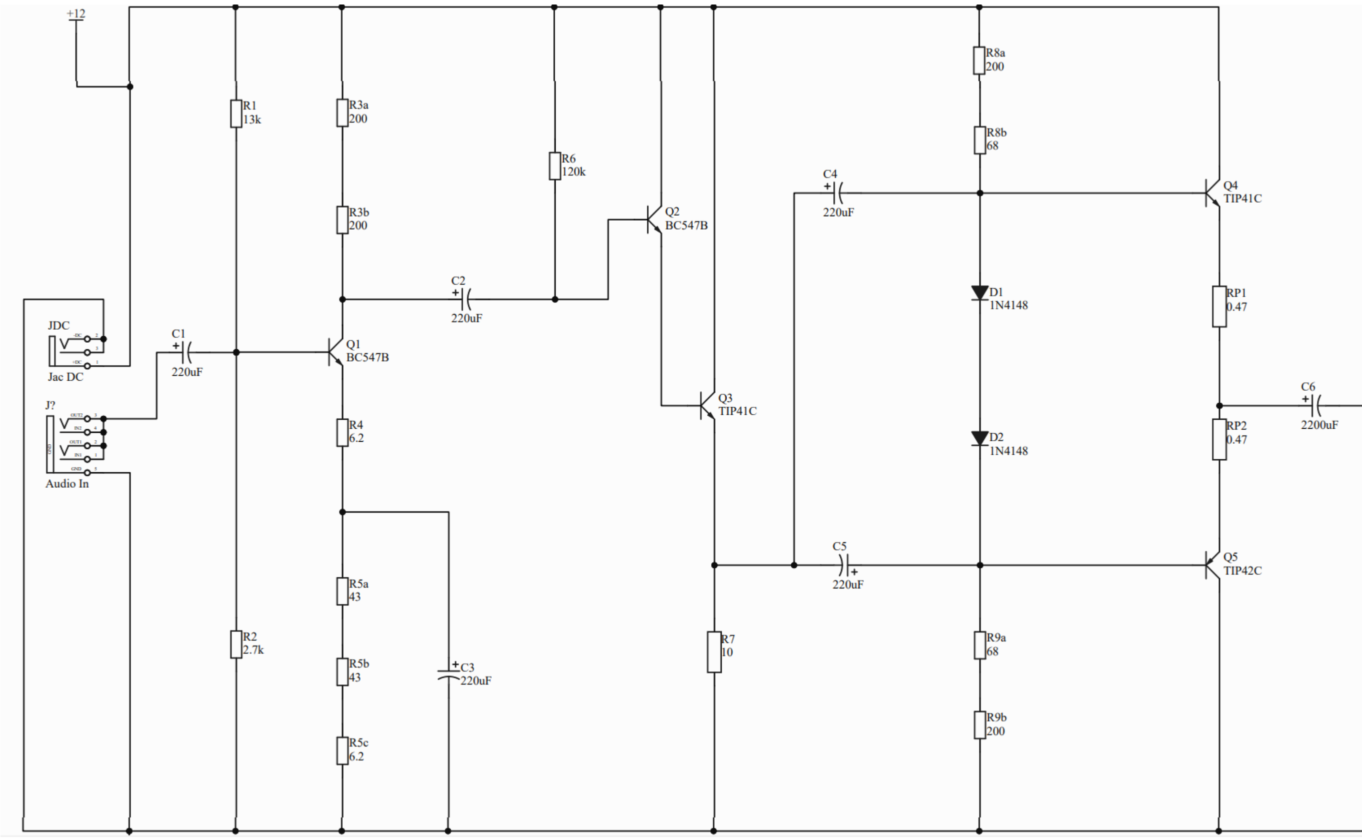

Figure 11: Schematic for exporting to PCB

6.4 PCB Preview

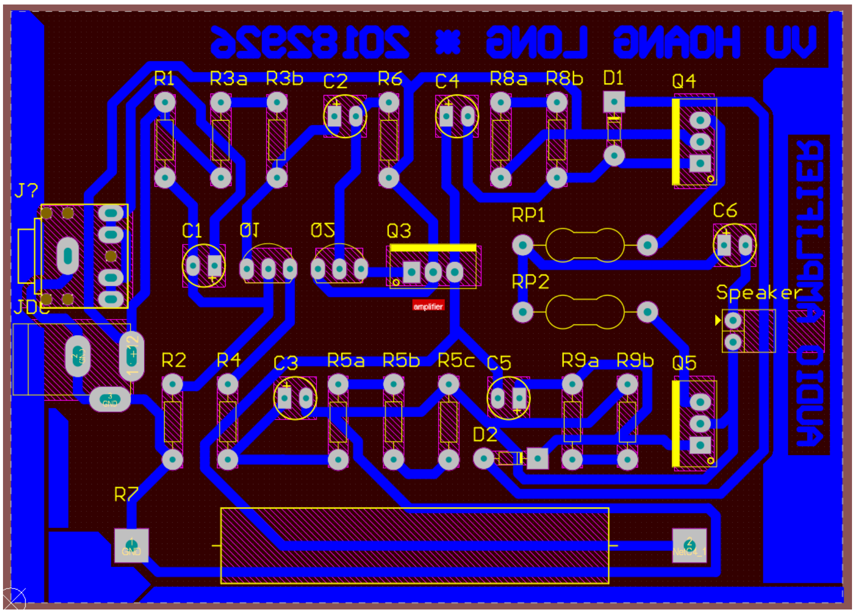

Figure 12: 2D View

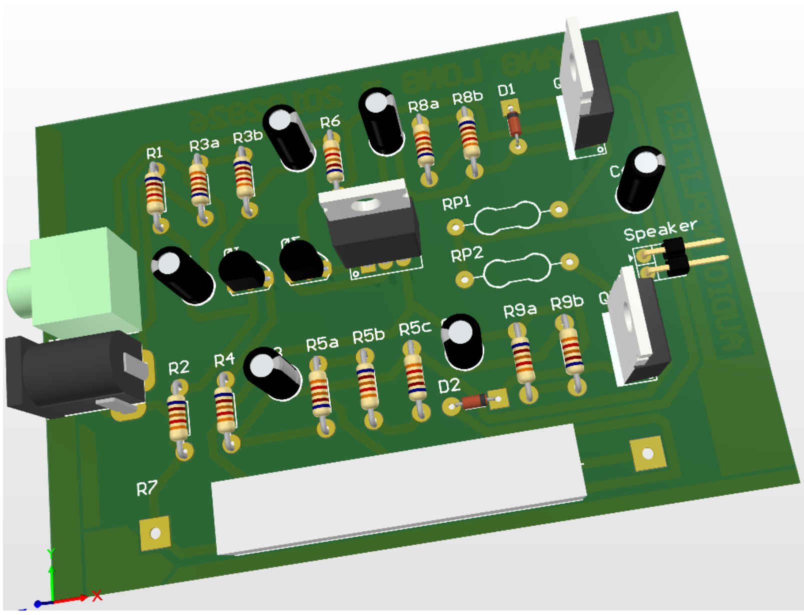

Figure 13: 3D View

6.5 PCB Layout

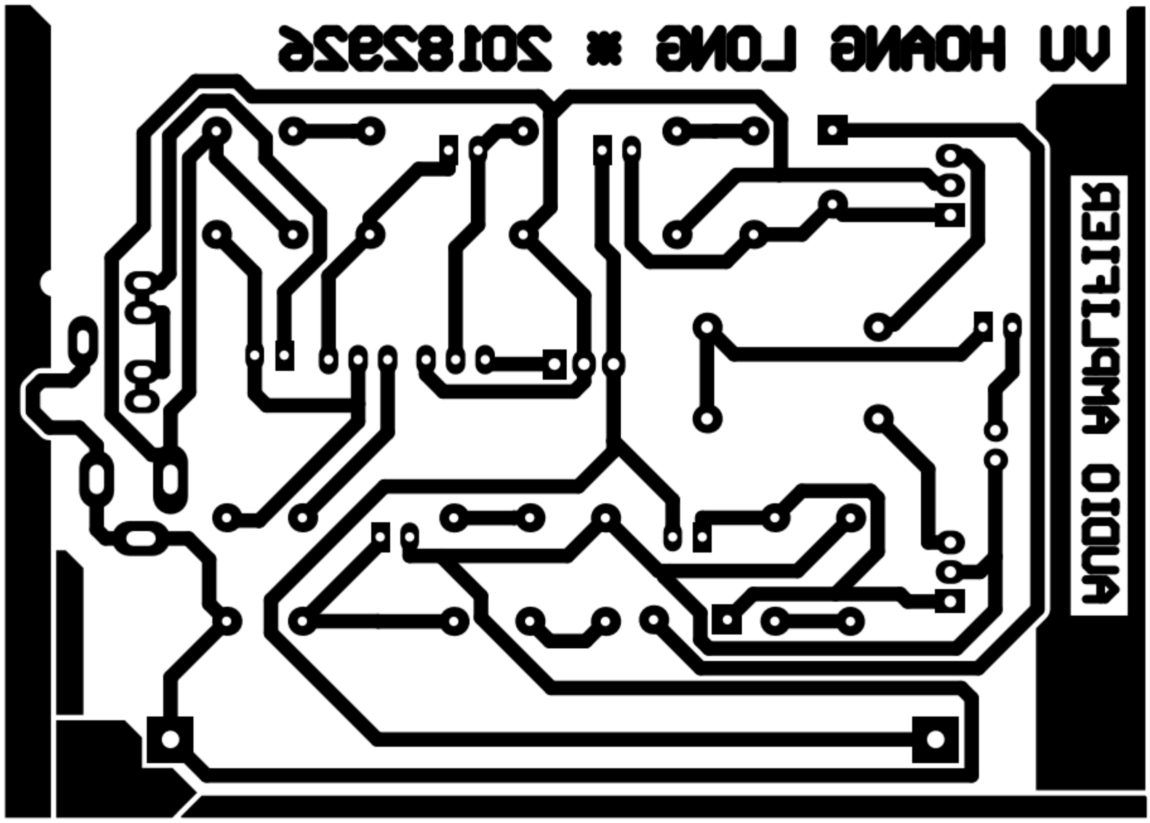

Figure 14: PCB Layout

Part IV
Making Product and Testing

7 Testing with Breadboard

Links to videos of breadboard testing: One Drive or Google Drive

8 Final PCB

Link to videos of PCB Testing: Google Drive

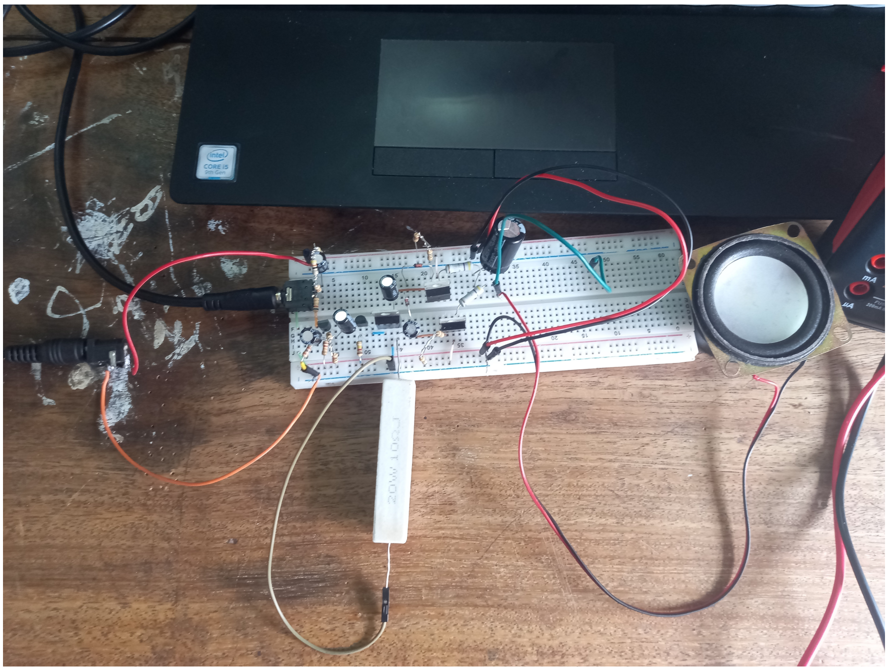

Figure 15: Breadboard Testing

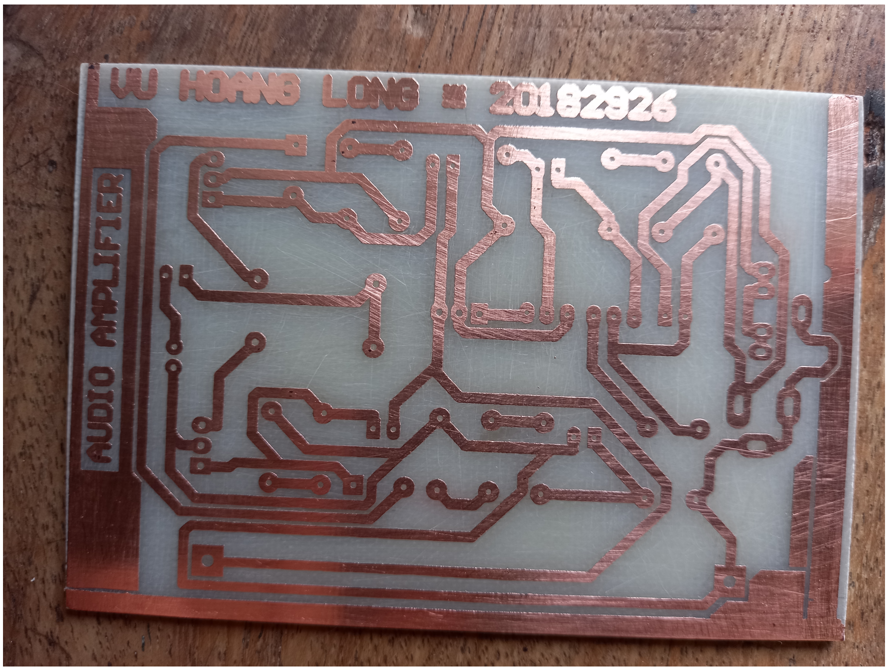

Figure 16: PCB After Printed and Cleaned

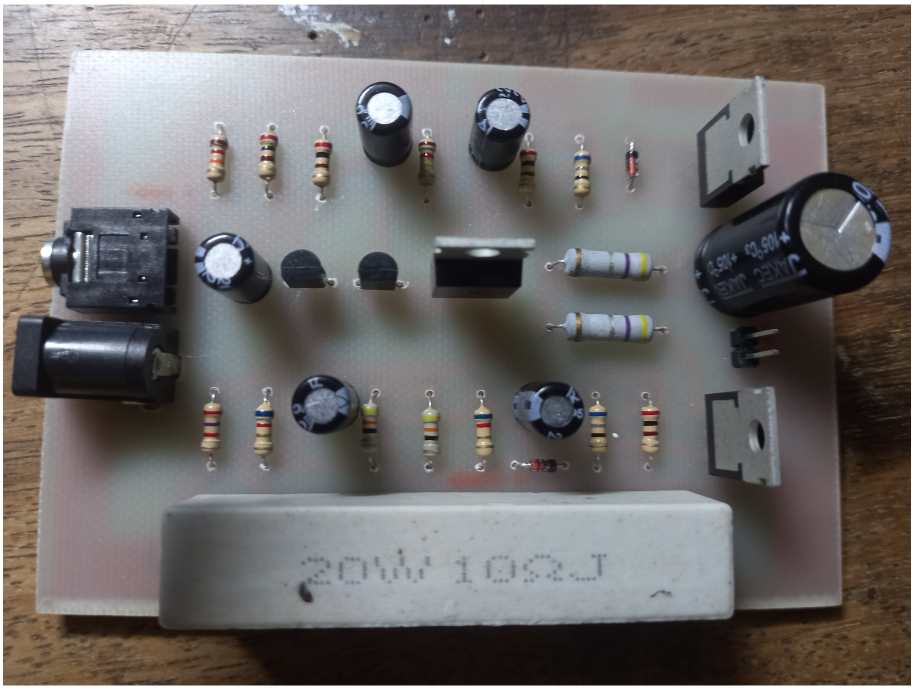

Figure 17: PCB Front Side

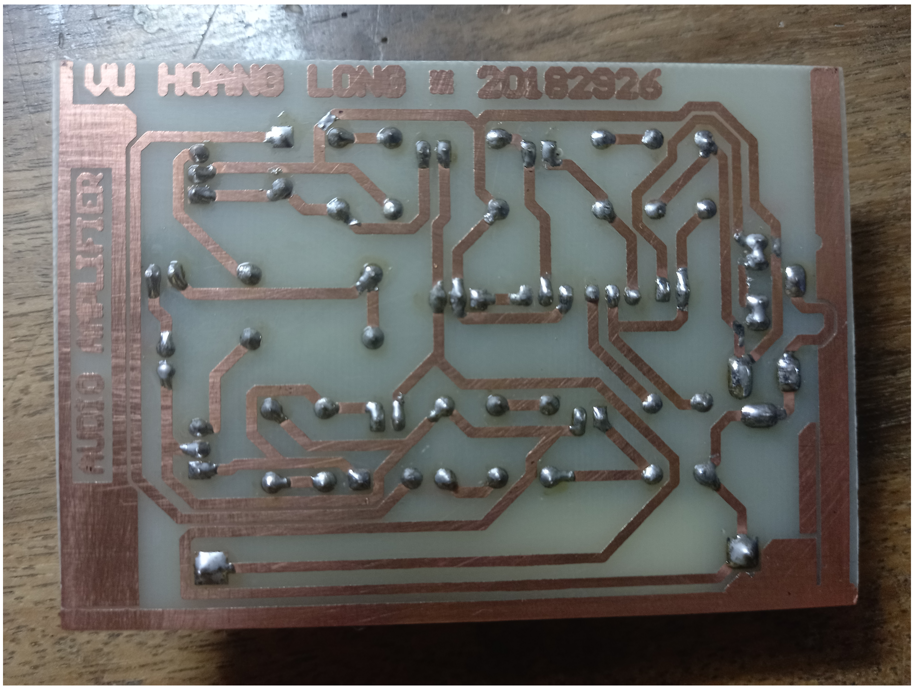

Figure 18: PCB Back Side

9 Comparison

	Calculation	PCB Measurement
Vin	50mV	50mV
Vout	2.35V	2.23V
Power	1.38W	1.24W
Gain	47	44.6

Figure 19: Comparison

The measurement video was shown in the above link.

Part V
Conclusion

Comprehensively, over many times of modifying and testing, finally my calculation results match with the simulation, and then with the breadboard testing and my final PCB. Respectfully, this process and those trials considerably helps me to fill up my lack of knowledge that I can not even consider without the time for this project. Moreover, I become more familiar with the use of some very effective electronics-related software such as ***Multisim***, ***Proteus***, ***Altium***, which will be furthermore very helpful for my higher studying on the field of *Electronics and Telecommunications*.

Anyway, though I have worked hard and achieve a desirable accomplishment, my final project seems not to be the best one. Within the significant development of technology, everyday I see many kind of audio amplifier, or in the other word loudspeaker, with the tiny size but burly sound, also very high resolution, etc. Nevertheless whatever the world was, I have tried and will try my best to understand the basis principle of what I learn, from the simplest thing, like this project. With this way of approach, I hope those essential knowledge will help me to accelerate my further studying and career.

On the way I gain my goal, without a great guide, I can not easily get it. Sincere thanks to my teacher Dr. Nguyen Vu Thang, who lighten the procedure step by step, so that I can get the right path to accomplish my project with the minimized consumed effort. Due to the limit of time, perhaps my product ends up by just a PCB, without the optimization of size and efficiency. Anyway, I am really looking forward to receive you feedback on my project so that I know my lackage and do better on the next projects. Once again, thank you very much for your devotion.

Thank you!

Reference

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