ĐẠI HỌC QUỐC GIA TP. HCM

TRƯỜNG ĐẠI HỌC BÁCH KHOA

BÀI TẬP LỚN MÔN HỌC

ELECTRONICS CIRCUITS

LỚP:TT01

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I. INTRODUCTION

A Bipolar Junction Transistor (BJT) operational amplifer is fundamental building block in an analog circuit which is a type of analog circuit amplifier used to amplify the difference between two input signals. This is typically a multistage amplifier with each stage is built by using BJTs which then create different type of circuits (Current mirror circuit, differential circuit, Common Emitter with resistor, etc.) with each circuit will provide amplification, stability, and low output impedance.

Basic concept:

The input signals are connected to the two base of the BJT in the differential circuit configuration and being processed by amplifying the differential between the two input signals and more ideally rejected all the common mode signal between the two inputs.

Key feature:

1. Amplify the diffrence between two input.
2. High voltage gain.
3. Low output impedance.
4. High speed performance.

Advantages:

- Superior linearity for high-accuracy applications.
- Fast response time due to the high transconductance of BJTs.
- Robust performance in high-frequency domains.

Disadvantages:

While BJT op-amps offer several advantages, they also come with challenges such as:

- Lower input impedance compared to MOSFET-based designs.
- Greater power consumption, which may limit their use in low-power applications.

- Thermal stability concerns, requiring careful design to mitigate issues like thermal runaway.

II. THEORY AND MATERIAL

1. CURRENT MIRROR.

A current mirror is a circuit that is designed to “mirror” a current from one active device (in this case the BJT) to another active device (BJT) in that circuit. Keeping the output current of these devices’ constant no matter how the loading is changed. This helps reduced the number of current sources required for the circuit in order to save space and cost for the circuit as well as improving the stability of the circuit. This is archived by figure 1. The I ref is connected to the first BJT which is then create the voltage between the base and emitter of the first transistor. Since the BJT are identically match hence the same V_{BE1} will be copy to the transistor and this voltage then create the current that output at I_{C2}.

For this amplifier circuit, we need the current mirror so that the current in the emmiter of the difference amplifier state can be controlled by the designer.

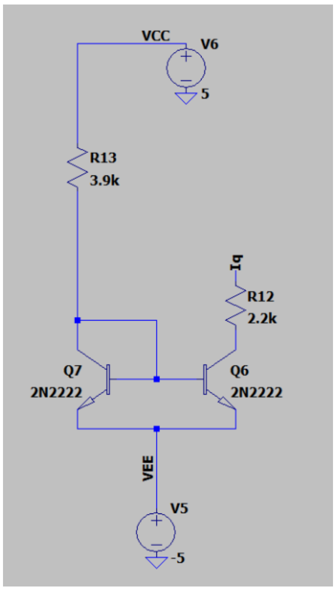

Fig 1.Configuration of the current mirror.

2. DIFFERENTIAL AMPLIFIER

The BJT differential amplifier is the most crucial part of the operation which consists of two BJTs (for this we using a pair a NPN transistors). That are coupled at the emitters to a current source (which is created by the current mirror circuit) and two equal but opposite in phase signal sources in each base.

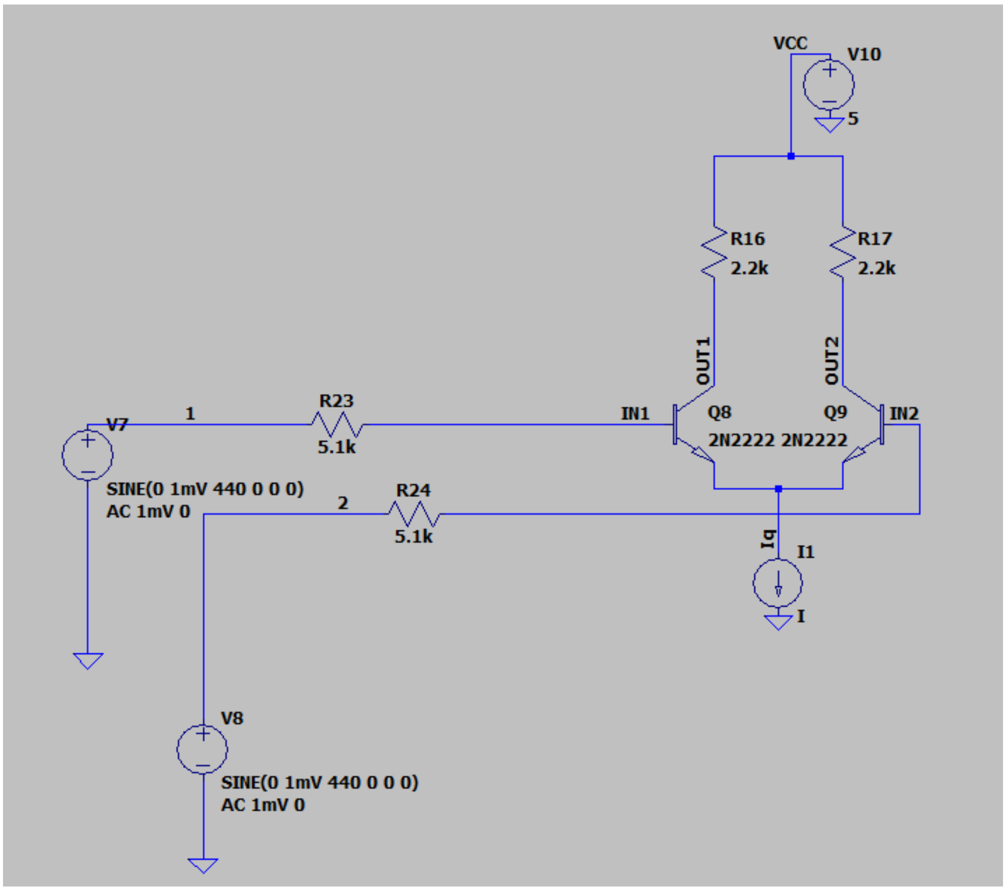

Fig 2. Basic configuration of a differential amplifier

The basic configuration is shown in the following figure 2.

The key characteristic for this stage is to amplify only the difference between the two-input signal and ideally reject all the common mode signal that exist between the two input signal, hence the Common Mode Rejection Ratio (CMRR) which is equal $\left|\frac{A_D}{A_{CM}}\right|$ will be infinite.

3. COMMON EMITTER WITH RESISTOR

A common emitter amplifier with a resistor in the emitter serves several critical roles in analog electronics. The addition of the emitter resistor significantly improves the performance and stability of the amplifier. The key points for this circuit is to bias stabilization, giving negative feedback which in turn improve the stability and linearity and set a predictable gain for the amplifier.

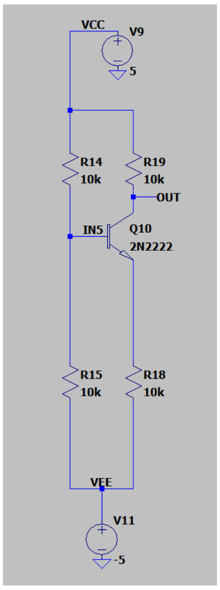

Fig 3. Common Emitter with resistor.

III. OUR PROJECT

The following figure is a basic configuration operational amplifier using BJTs.

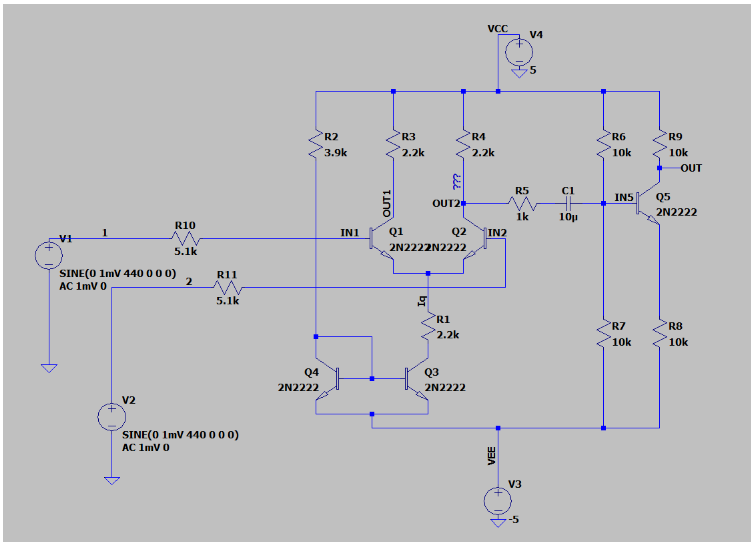

Fig 4. Operational amplifier using BJTs.

DC analysis:

We apply the KVL loop on the left side that leaves us an equation:

$$0 + I_{B1} \times R_{10} + 0.7 + 2I_{E1} \times R_1 - 5 = 0\,(1)$$

We have that:

$$(\beta + 1)I_B = I_E\,(2)$$

Hence from (1) and (2) we got:

$$I_{B1} = I_{B2} \approx 4.7\mu A$$

$$I_{E1} = I_{E2} \approx 0.964mA$$

$$I_{C1} = I_{C2} \approx 0.964mA$$

$$I_E \approx 1.928mA$$

Which is approximately correct for the current source I_1 that we supply in the current mirror circuit.

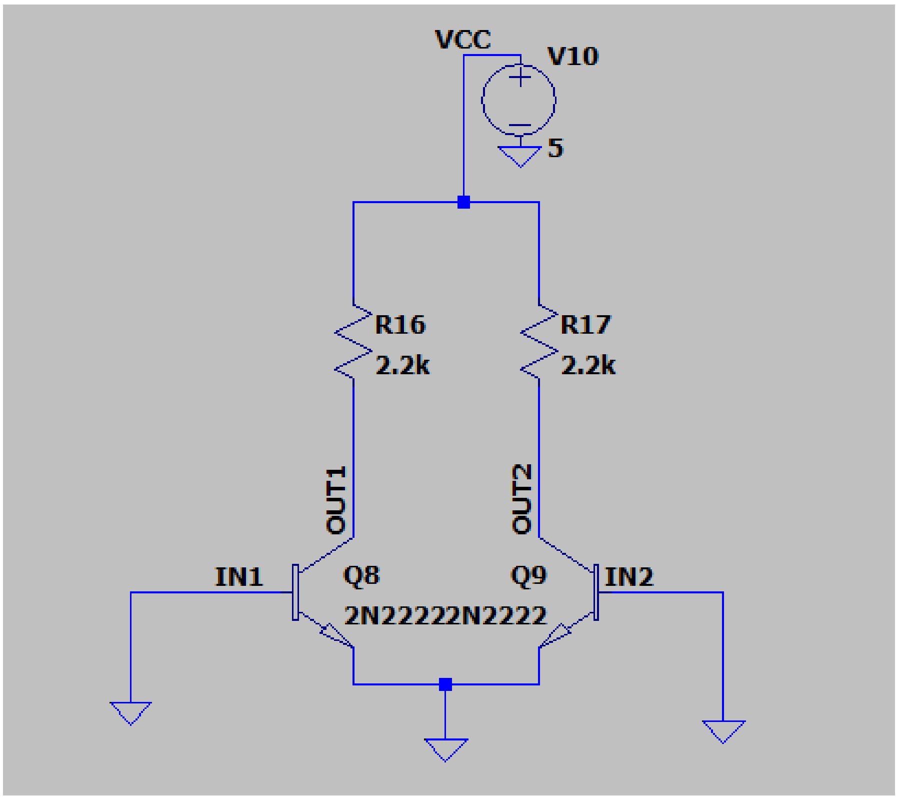

Fig 5. DC analysis for the differential circuit.

Then we calculate for the voltage output. We have:

$$V_{01} = V_{02} = 5 - R_3 \times I_{C1}$$

$$V_{01} = V_{02} = 2.8729\text{V}$$

For the output at the common emitter with resistor we changed the circuit to the Thevenin equivalent circuit:

Then we solve for the DC analysis:

$$0 - (-5) = I_{B5} \times R_{BB} + 0.7 + I_{E5} \times R_8$$

Hence the value for I_{B5} is:

$$I_{B5} \approx 2.13 \mu A$$

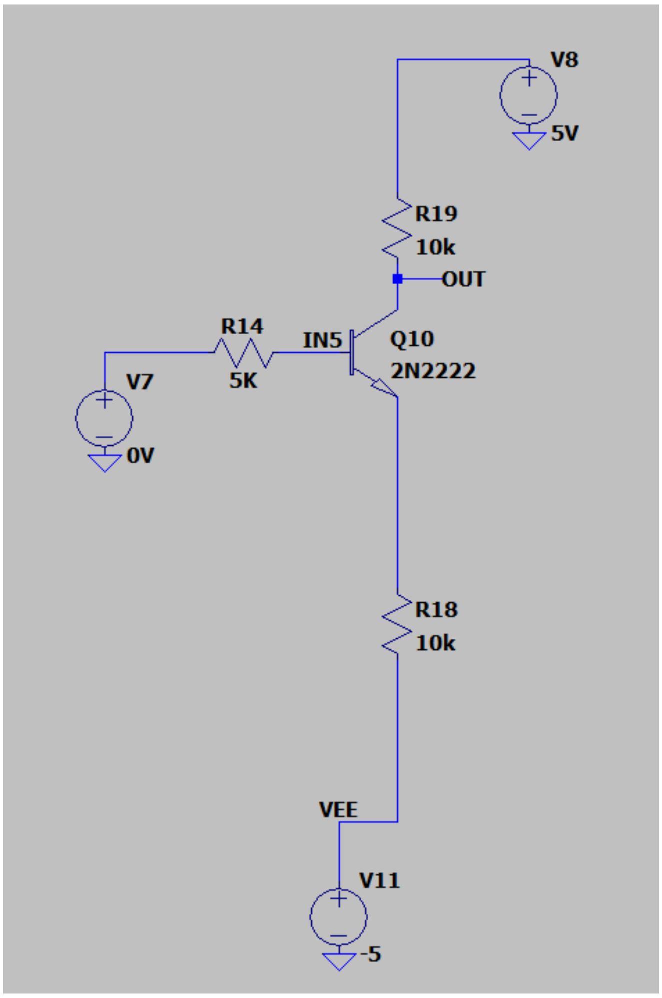

Fig 6. Thevenin equivalent circuit.

$$I_{E5} = (\beta+1) \times I_{B5} \approx 0.43mA$$
$$I_{C5} = \beta \times I_{B5} \approx 0.43mA$$

$$V_{C5} = 5 - I_{C5} \times R_9 = 0.7V$$

$$gm5 = \frac{I_{C5}}{V_T} = 0.017$$

$$R_{\pi 5} = \frac{\beta}{gm} = 11.76k\Omega$$

AC analysis:

1. **Differential stage:**

A. Differential mode:

From the following circuit:

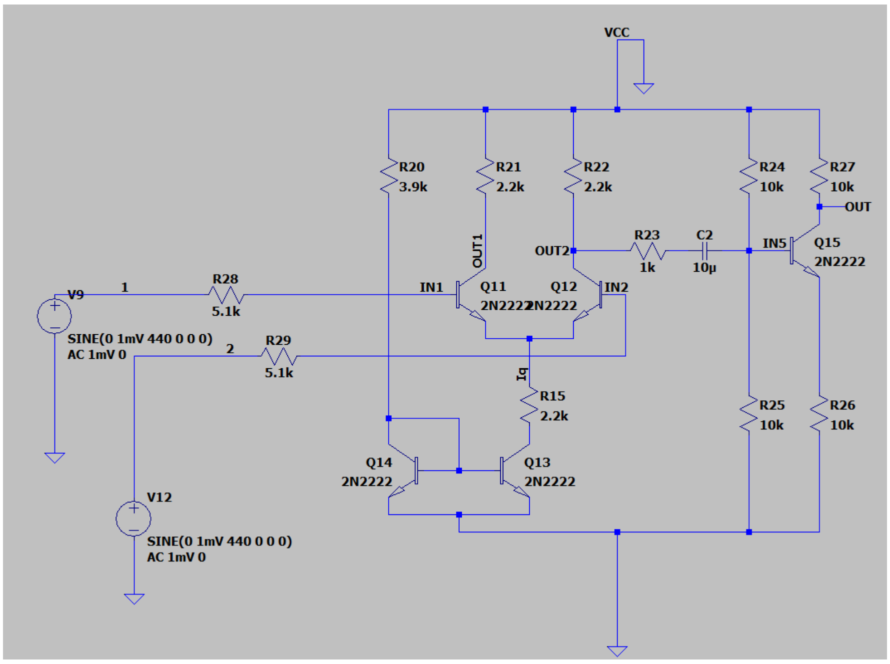

Fig 7. AC analysis for the circuit.

Which will give this equivalent circuit:

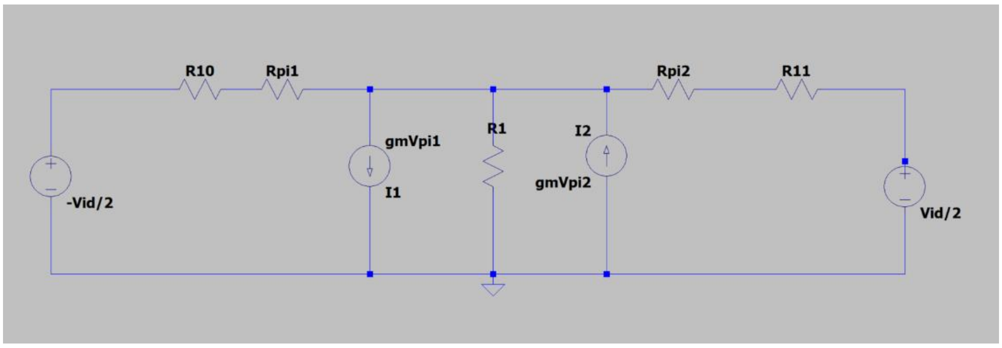

Fig 9. Differential equivalent circuit.

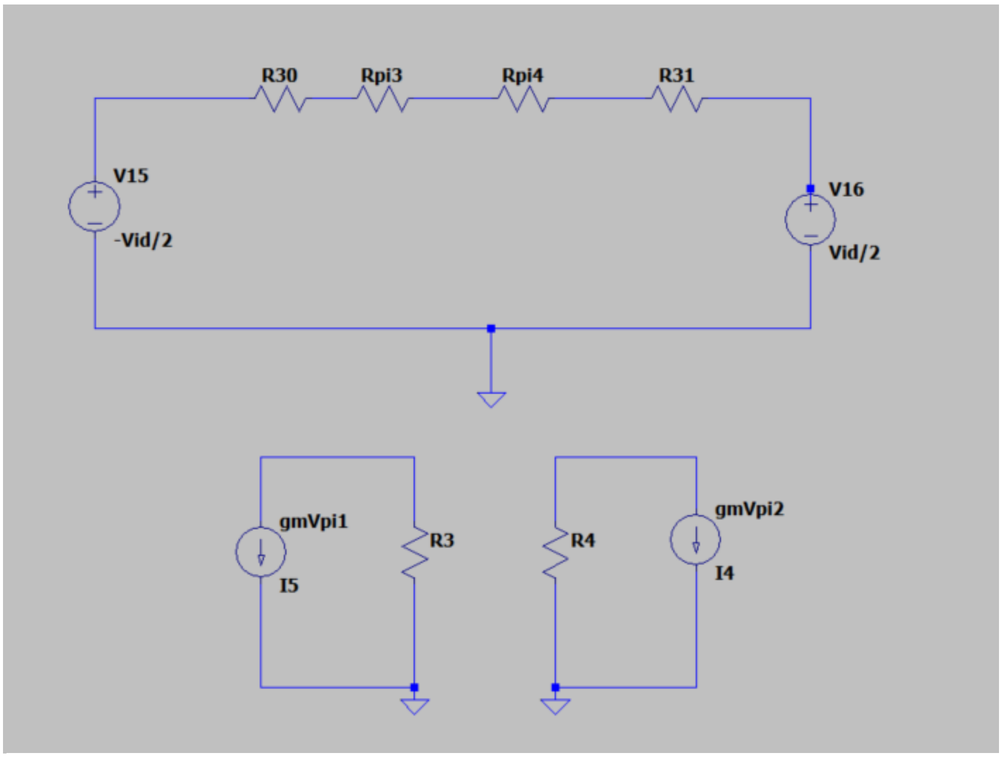

Fig 8. Equivalent circuit

We have obtained the following parameters from the DC analysis:

$$gm_1 = gm_2 = 0.04$$
$$R_\pi = R_\pi = 5K\Omega$$
$$\beta = 200$$

From those parameters and the given π-model, we can calculate the V_{od}:

$$V_{od} = -gm_2 \times V_{\pi 2} \times R_4$$
$$V_{od} = -gm_2 \times \frac{R_{\pi 2}}{R_{\pi 2} + R_{11}} \times \frac{V_{id}}{2} \times R_4$$
$$V_{od} = -20 V_{id}$$

B. Common mode:

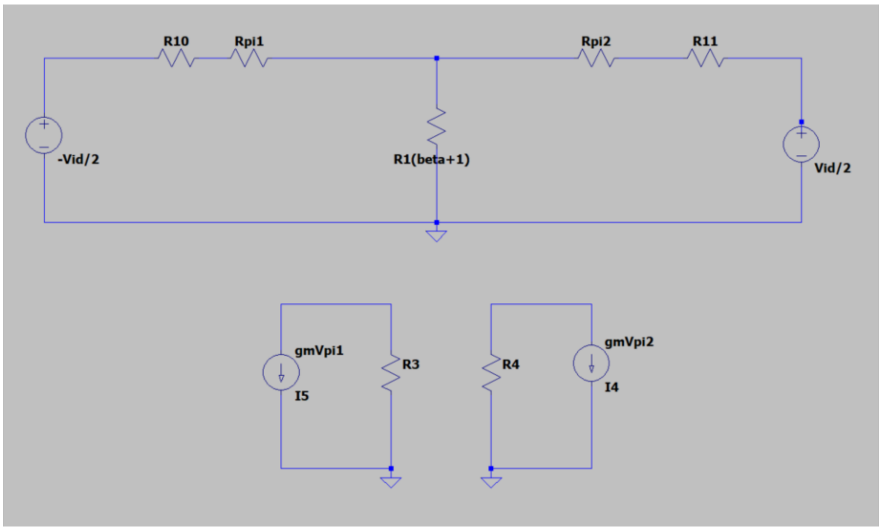

Fig 11.Common mode equivilant circuit.

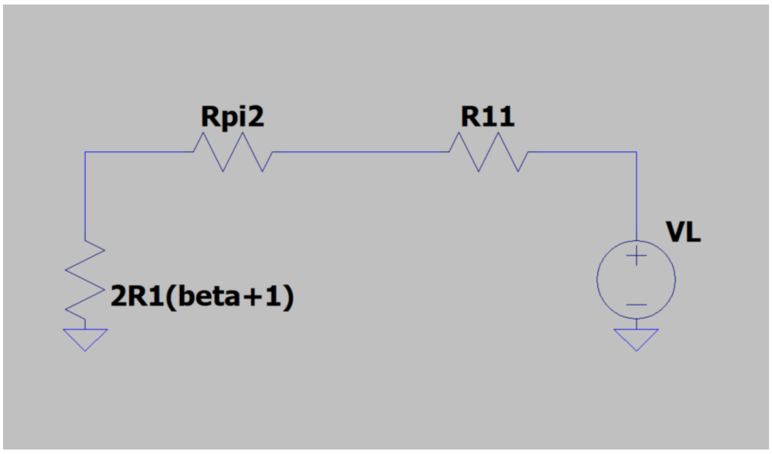

Fig 10.Common mode equivalent circuit.

We calculate for the output in the common mode:

$$V_{oc} = -gm_2 \times V_{\pi 2} \times R_4$$

$$V_{oc} = -gm_2 \times \frac{R_{\pi 2}}{2 \times R_1 \times (\beta + 1) + R_{\pi 2} + R_{11}} \times V_C \times R_4$$

$$V_{oc} = -0.49 \times V_c$$

Combine with the output voltage obtained in the differential mode, we can obtain the Common Mode Rejection Ratio:

$$\text{(CMRR)} = \left| \frac{A_d}{A_{CM}} \right| = \left| \frac{20}{0.49} \right| = 40.82$$

2. Common emitter with resistor

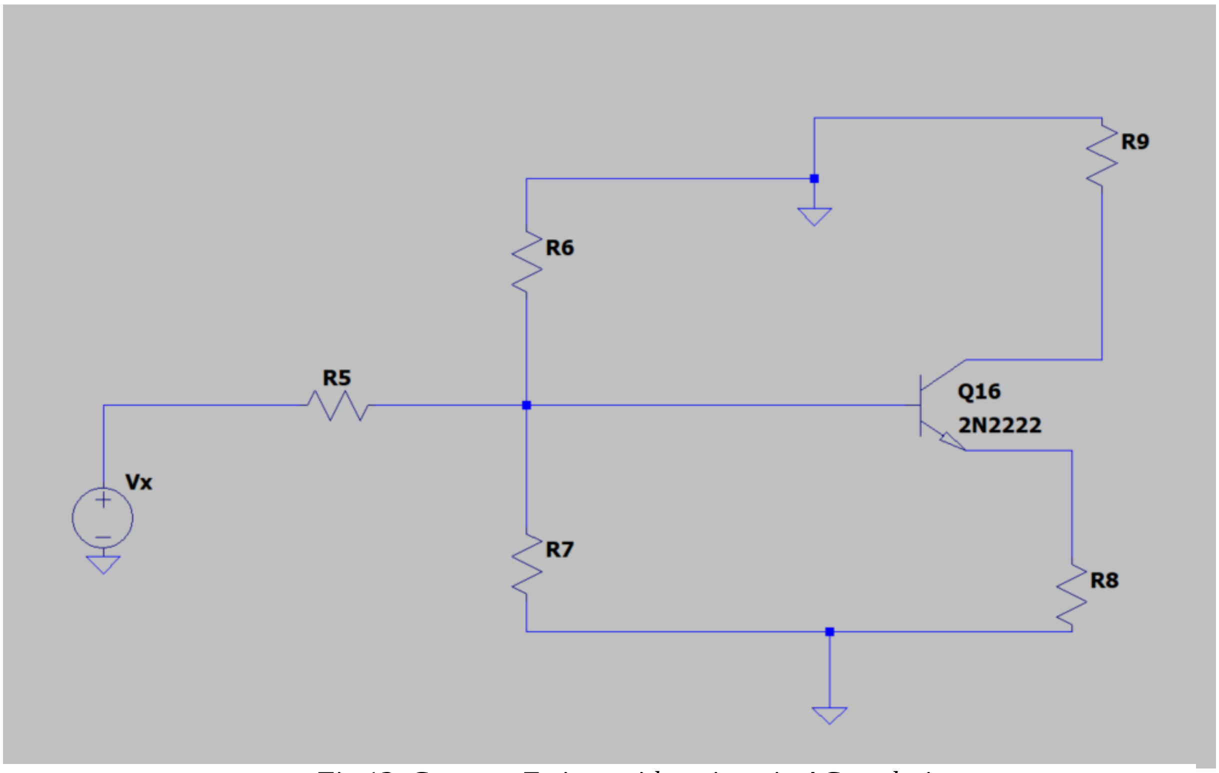

Fig 12. Common Emitter with resistor in AC analysis

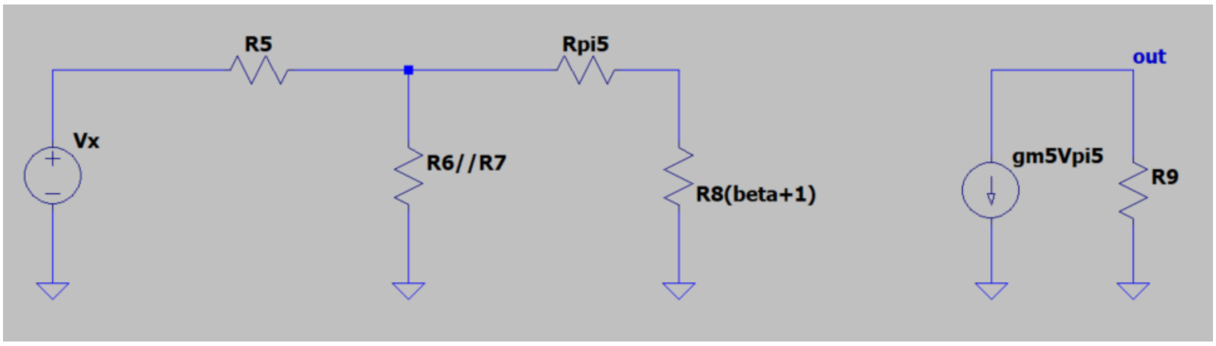

Fig 13. Equivalent circuit.

We now calculate the output voltage as shown in fig 13.

$$V_{out} = -gm_5 \times V_{\pi 5} \times R_9$$

$$V_{out} = -gm_5 \times \left(\frac{R_{\pi 5}}{R_{\pi 5} + R_8(\beta+1)} \times \frac{[R_{\pi 5} + R_8(\beta+1)]//R_{67}}{R_5 + [R_{\pi 5} + R_8(\beta+1)]//R_{67}} \times V_x \right) \times R_9$$

=33.36mV

With $gm_5 = 0.017$ and $R_{\pi 5} = 11.76 \mathrm{K}\Omega$

Then we combine with the DC analysis state which will give us the output voltage now at:

$$V_{out} = 0.7 + 0.03336 = 0.73336 \text{ (V)}$$

As shown in the simulation.

3. Simulation and Application

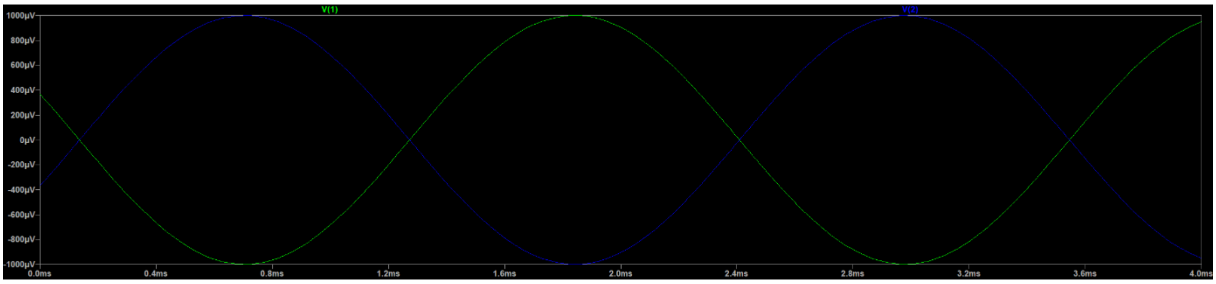

Fig 14. Input signal in LTSpice.

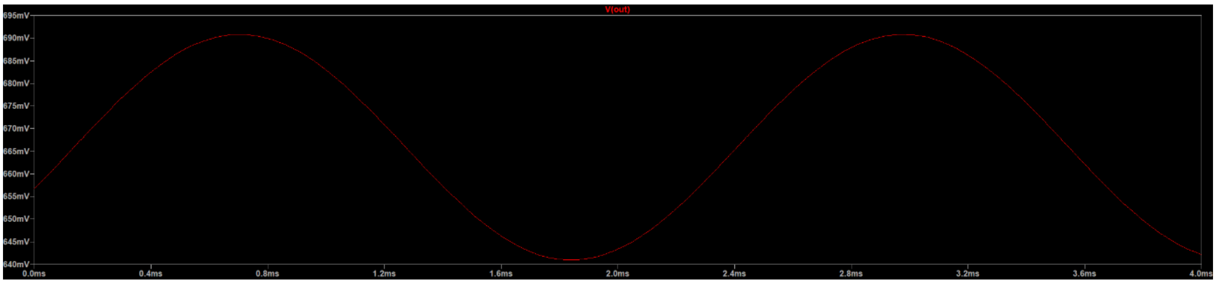

Fig 15. Amplified output signal.

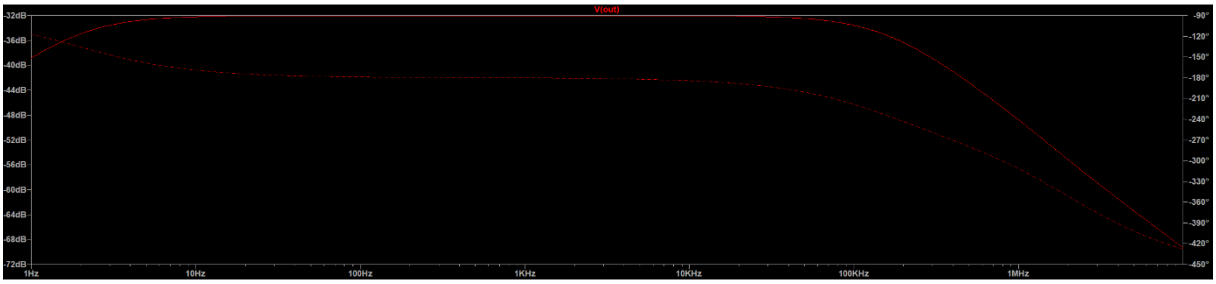

Fig 16. Frequency repsonse of the designed circuit.

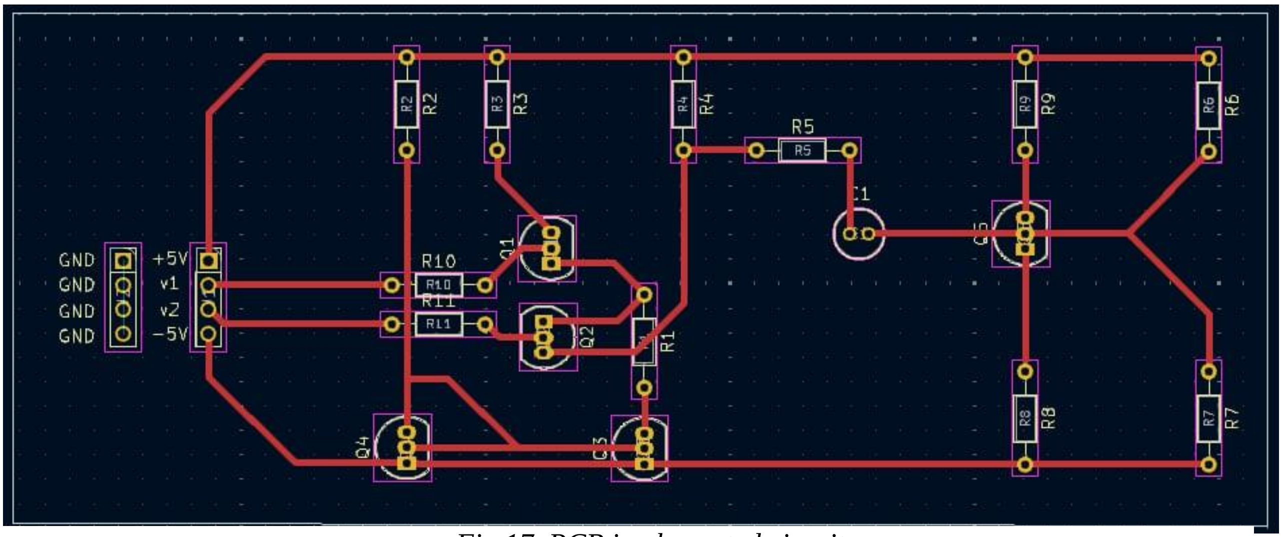

Fig 17. PCB implemented circuit.

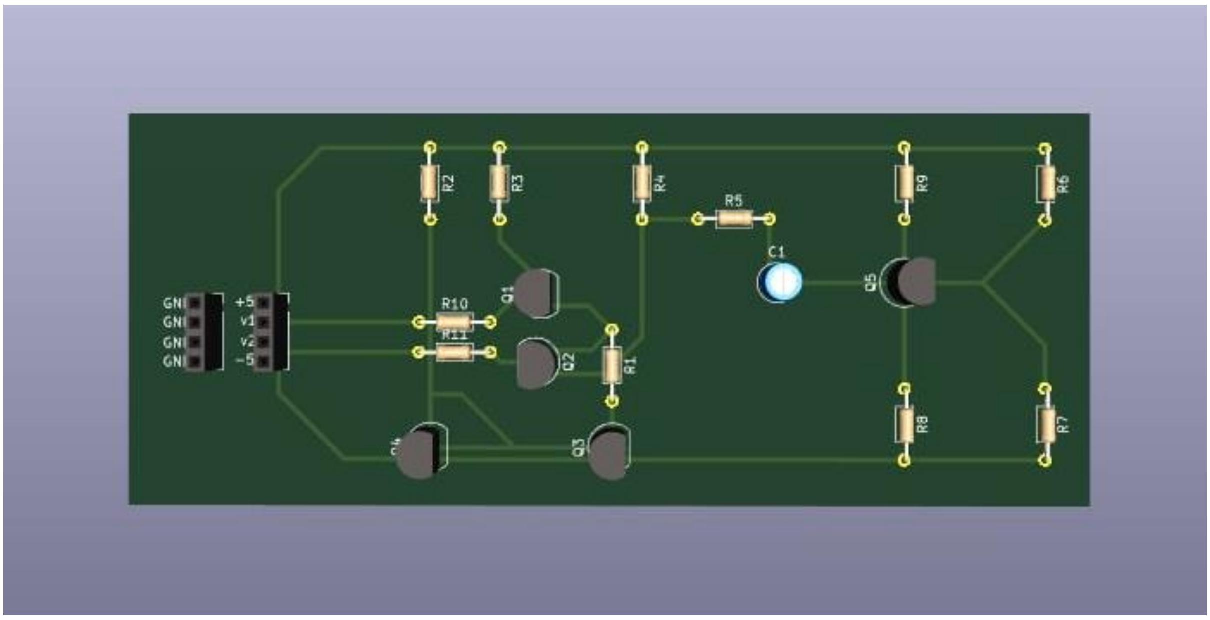

Fig 18.PCB implemented circuit.

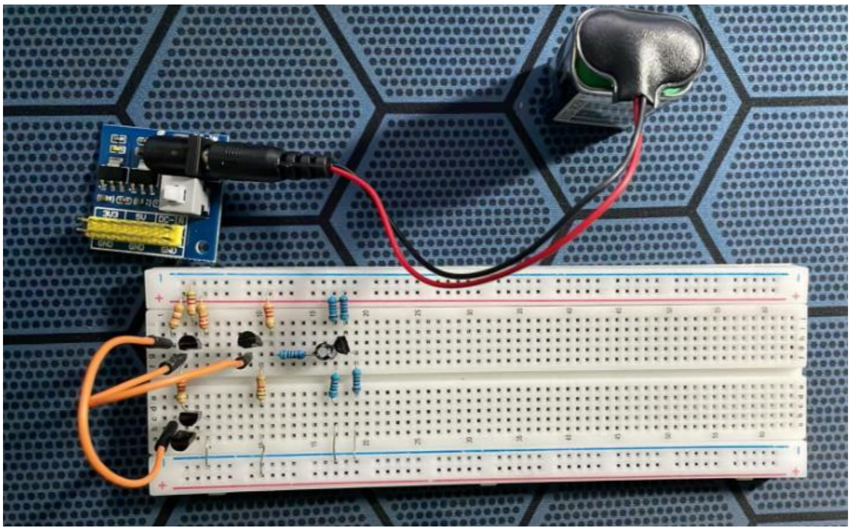
Fig 19. Circuit in real world.

Fig 19. Shown the implemented circuit in real world using 2N2222 NPN BJTs and varies of resistors with a 9V battery supplying the voltage to the 5V DC converter circuit which is then supplied to the breadboard both 5V and -5V. However, due to the lack of equipment we have not yet capture the amplified output.

4. Conclusion

Throughout the course we have learned and can designed a simple amplifier circuit. Although this circuit is not yet perfected but from this will give us the base to furthermore design better and more sufficient as well as elegant circuit in the future.