Bilkent University

EEE313 Lab 4 Report

Two-stage BJT amplifier

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Introduction

This lab aims to amplify a signal using a bipolar junction transistor as a common emitter amplifier. For this, the data sheets of BC238, BD135, and BD136 transistors were examined, and SPICE models were found. The circuit model of the Two-stage BJT Amplifier: Common Emitter stage cascaded with push-pull voltage buffer is as follows.

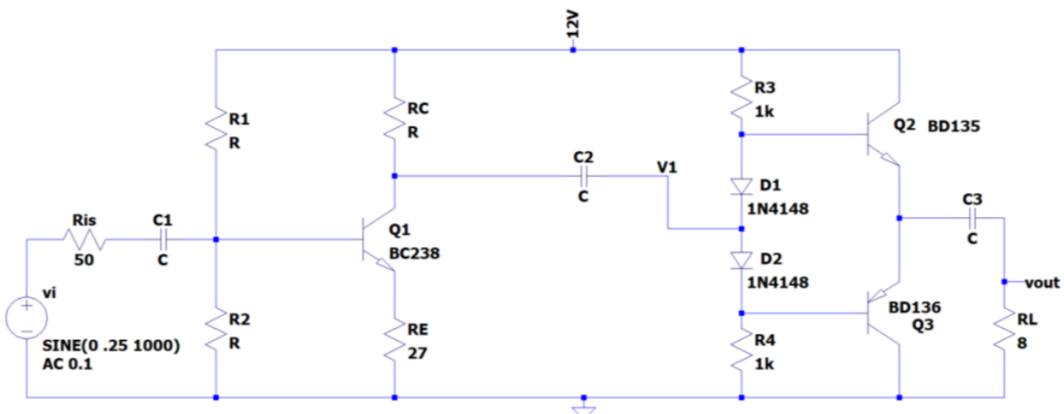


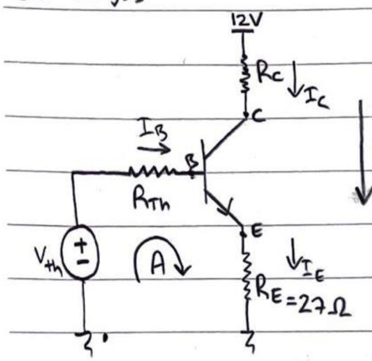
Figure 1: Two-stage BJT amplifier circuit

Software

A1) Finding the R_1, R_2, and R_c

In this part, firstly, AC analysis was performed, and R_c was calculated as 400 ohms using the gain values and information given in Hint 1. Then, for DC analysis, β value was selected as 300, and R_1 and R_2 values were chosen as 32k ohm and 3k ohm; as a result, I_B and I_C values were found. KVL was performed with the obtained values , and the V_{CE} value was found. DC and AC analysis calculations are as follows.

DC Analysis



$\beta = 300$, $V_{BE(ON)} = 0.7V$

$R_{th} = R_1 // R_2$

$V_{th} = 12 \cdot \dfrac{R_2}{R_1 + R_2}$

from KVL at A

$V_{th} = I_B R_{th} + V_{BE} + I_E R_E$

$V_{th} = I_B R_{th} + V_{BE} + (\beta + 1) I_B R_E$

$V_{th} = I_B R_{th} + 0{,}7 + 301 \cdot I_B \cdot 0{,}027$

$$I_B = \frac{V_{th} - 0{,}7}{R_{th} + 301 \cdot 0{,}027}$$

R_1 and R_2 are chosen as $32k\Omega$ and $3k\Omega$

So, $I_B = 30{,}23\,\mu A$ and $I_C = 9{,}07 mA$

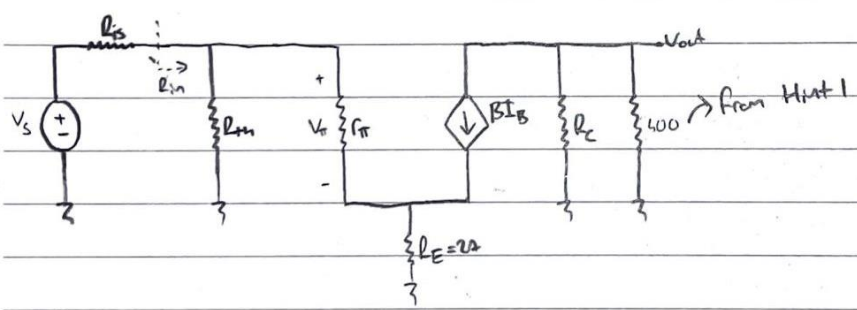
KVL at B

$12 - I_C R_C - V_{CE} - I_E R_E = 0$

$V_{CE} = 12 - 9{,}07 \cdot 0{,}4 - 9{,}1 \cdot 0{,}027$

$V_{CE} = 8.13V > V_{CE(SAT)}$

AC Analysis



$A_{v_{all}} = \dfrac{V_{outall}}{V_{inall}} = -5$ and $A_v = \dfrac{V_{out}}{V_{in}} = -10$

$V_{out} = -\beta I_B \cdot R_C$, $V_{outall} = -\beta I_B (R_C // 400)$

$V_{in} = V_{inall}$

$$\frac{A_v}{A_{vall}} = 2 = \frac{V_{out}}{V_{outall}} = \frac{-\beta I_B \cdot R_C}{-\beta I_B (R_C // 400)} \Rightarrow \frac{R_C}{R_C // 400} = 2 \rightarrow R_C = 400\,\Omega$$

Figure 2: DC and AC analysis

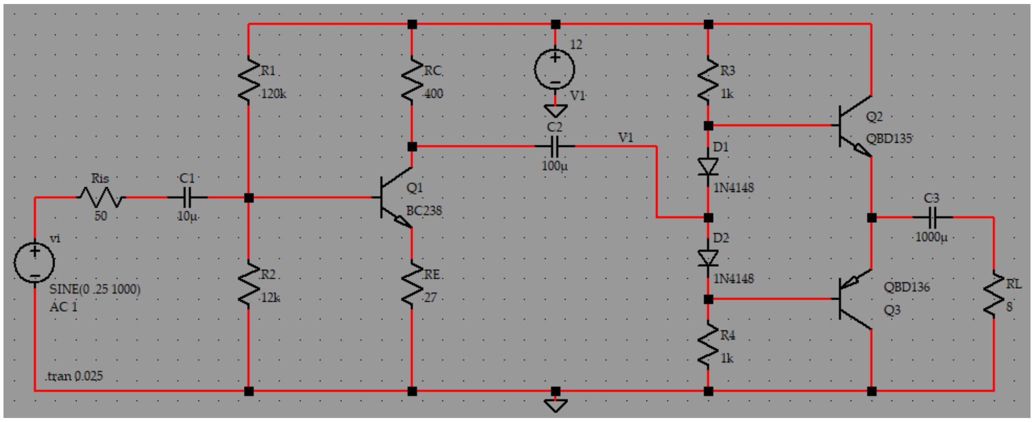


Figure 3: Two-stage BJT amplifier

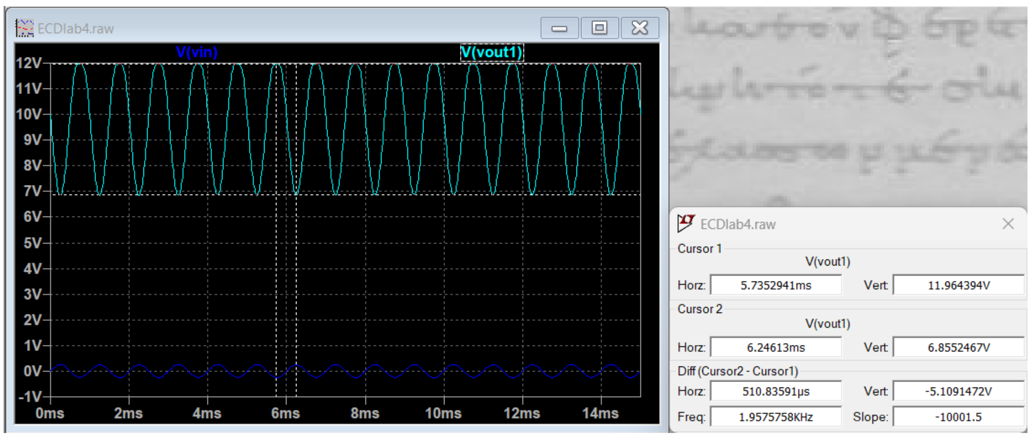


Figure 4: Output voltage of the first stage

When the output value of the amplifier's first stage is divided by the 0.5V input value, the result is -10.22, which is slightly less than the desired gain value of -10.

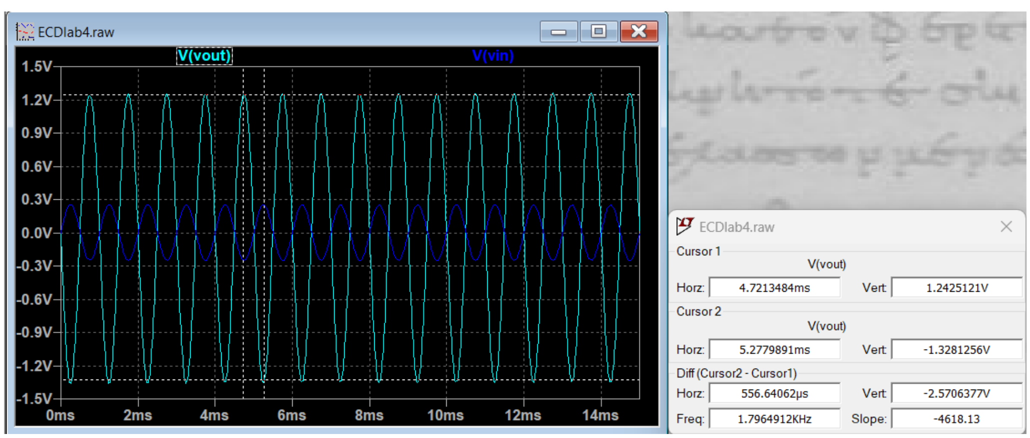


Figure 5: Output voltage of the overall circuit

When the output value is divided by the 0.5V input value, the overall gain is -5.14, slightly less than the desired gain value of -5. Selected resistor values satisfy specifications for gain.

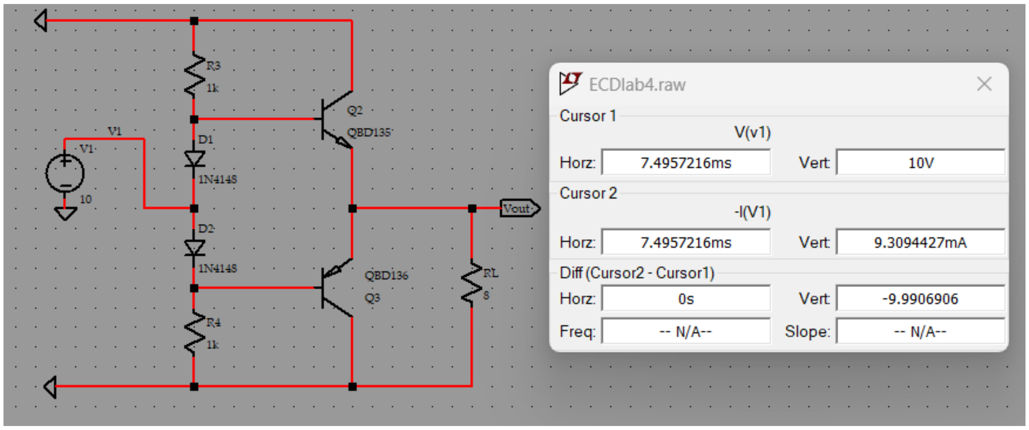


Figure 6: Rin seen from point V1 to the right

When the calculation is made using the test source for R_{in} seen from point V1 to the right, the result is 1.07k ohm. The calculation for the R_{pi} required to measure the input and output resistance of the amplifier is as follows.

$$g_m = \frac{I_C}{V_T} = \frac{9.22}{0.026} = 354\ mA/V$$

$$r_\pi = \frac{\beta}{g_m} = \frac{300}{354} = 846\ \Omega$$

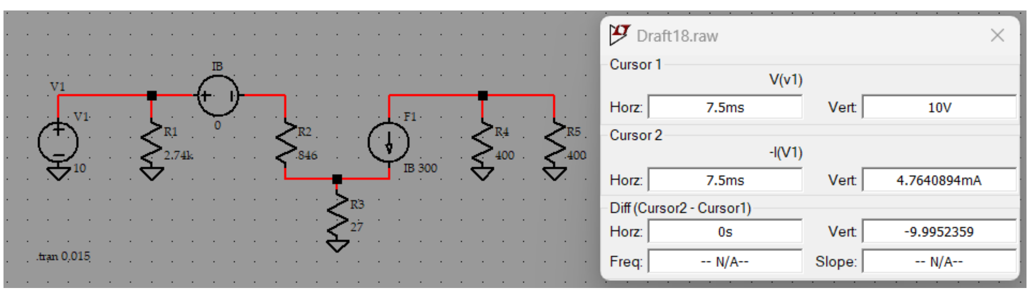


Figure 7: Input resistance

When the calculation is made using the test source for input resistance, the result is 2.1k ohm.

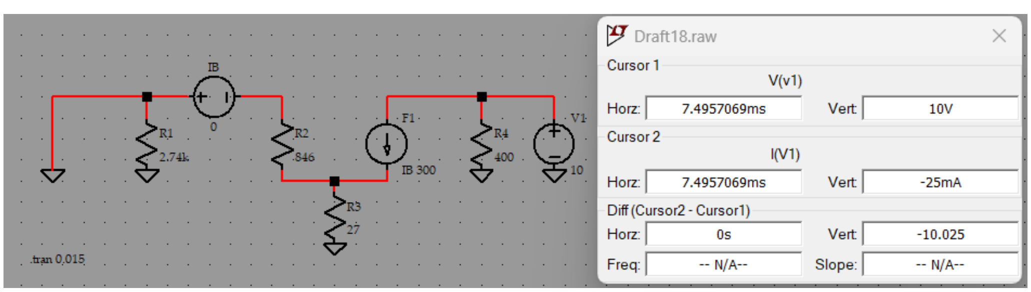


Figure 8: Output resistance

When the calculation is made using the test source for input resistance, the result is 0.4k ohm.

Figure 9: Q-point values of Q1, Q2, and Q3

	CALCULATED VALUE	MEASURED VALUE	ERROR
I_C of Q1	9.07 mA	9.22 mA	1.65%
V_{CE} of Q1	8.13 V	8.06 V	0.86%

Table 1: Q-point values of Q1

A2) Finding the f_L and f_H

The magnitude Bode plot of the output has been plotted for this part. When this plot is examined, it is seen that the maximum value is 14.15 dB, which is very close to the value where the gain is -5, that is, 20log (|-5|) = 13.99 dB.

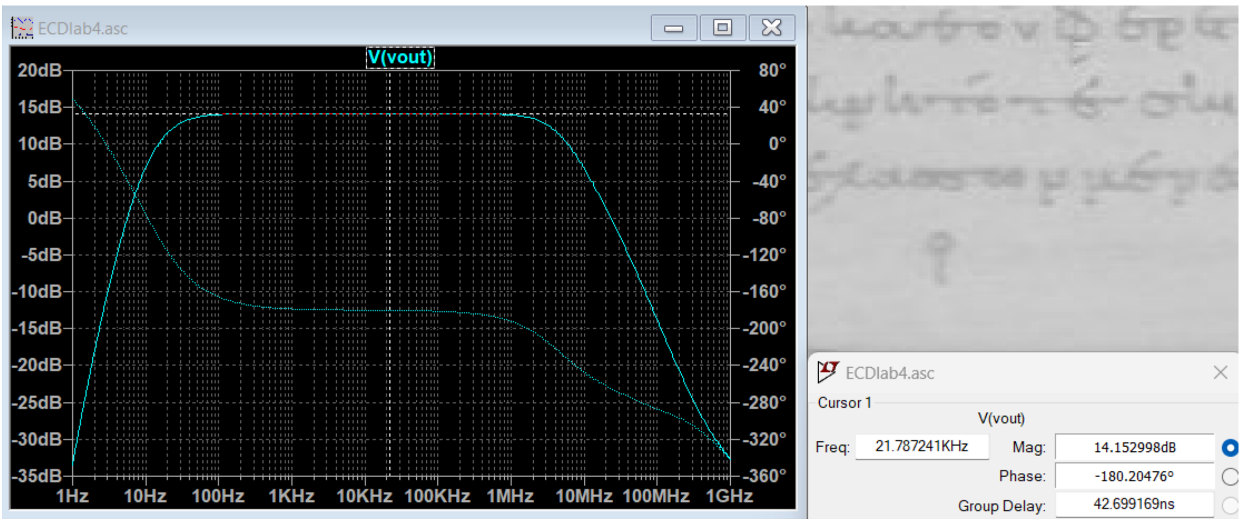


Figure 10: the top point of the dB curve

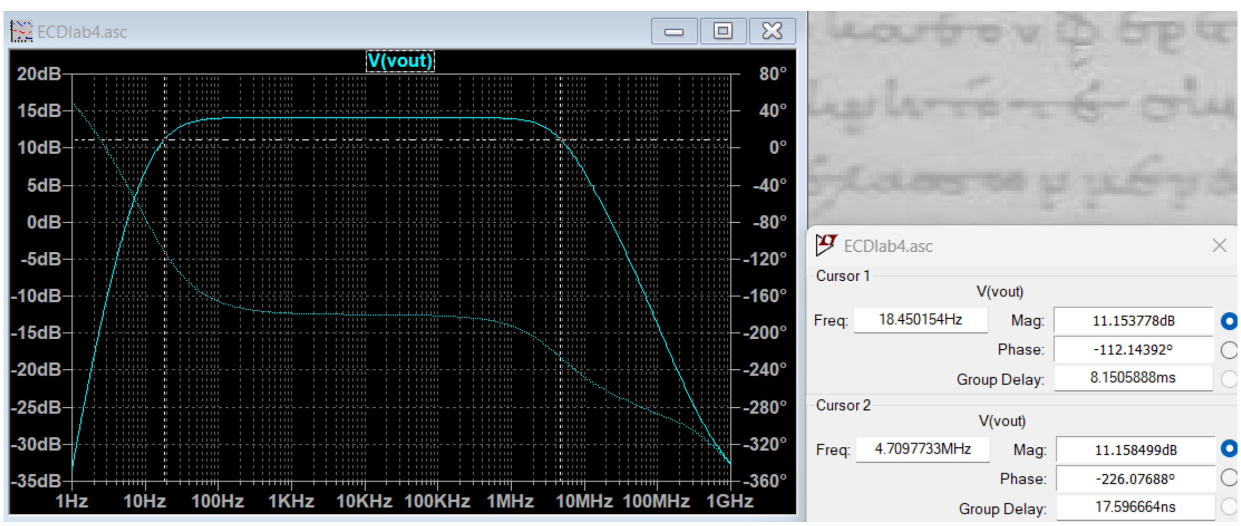


Figure 11: Frequencies of f_L and f_H

To determine the f_L and f_H values, which are the -3dB low and high cutoff frequencies of the amplifier, the frequency values of two points on the graph, which had the obtained value by subtracting 3 dB from the maximum value of 14.15 dB, were examined. These values are 18.45 Hz and 4.71 MHz, respectively.

A3) The Purpose of Diodes

The purpose of the diodes in this circuit is to prevent the base-emitter voltage from falling below the 0.7 V limit. In other words, thanks to the diodes, BJTs are always in the ON state, and a smooth curve graph is obtained. The output graph obtained after shorting the D1 and D2 diodes is as follows.

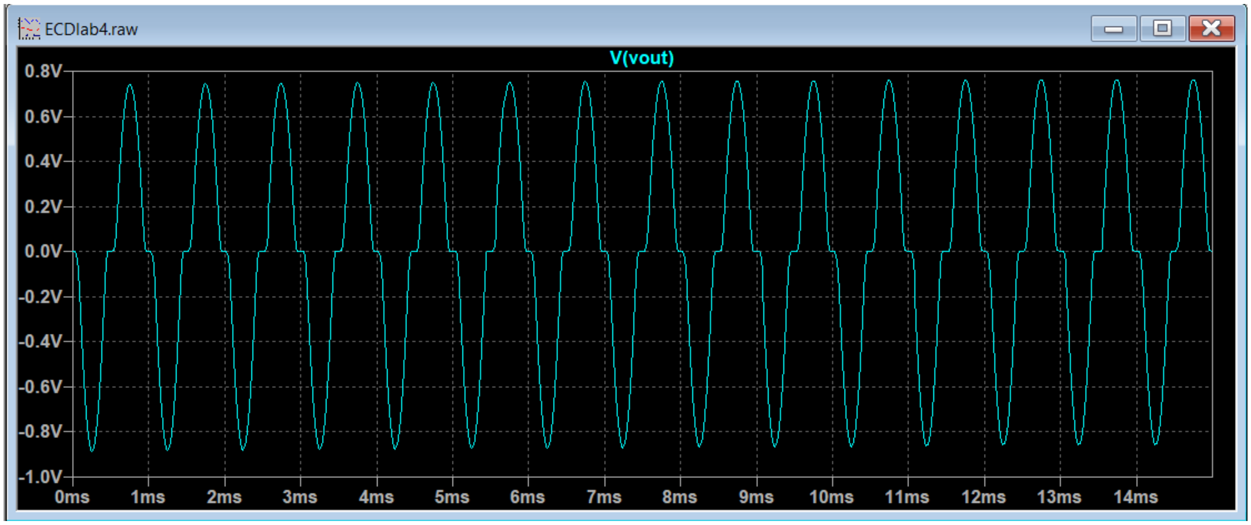


Figure 12: The output voltage when D1 and D2 diodes are shorted

Hardware

For the R_C, R_1, and R_2 values, the closest values found in the laboratory, 390 ohms, 33k ohms, and 3.3k ohms, were chosen, respectively. The circuit created with the obtained values is as follows.

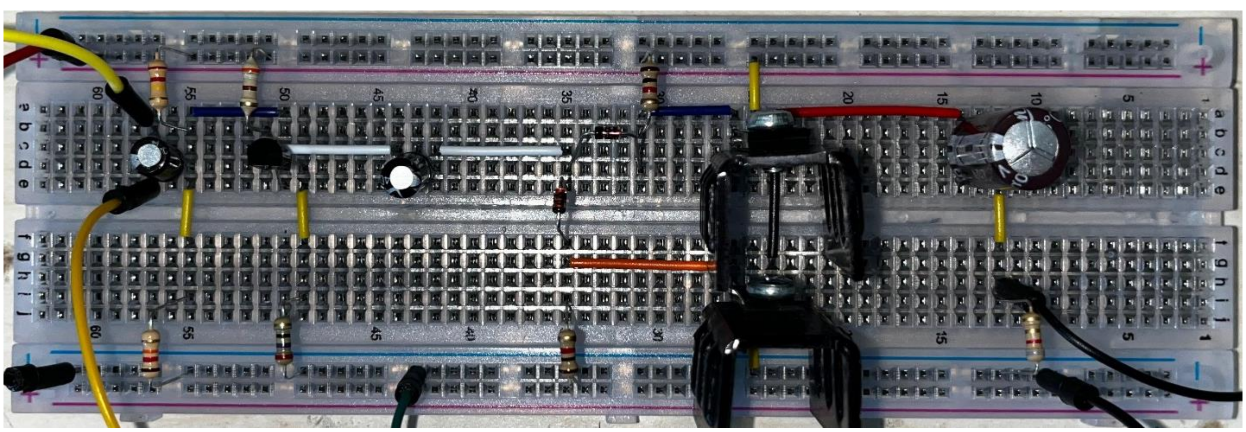


Figure 13: The Common Source Amplifier Circuit

B1) Q-point Values

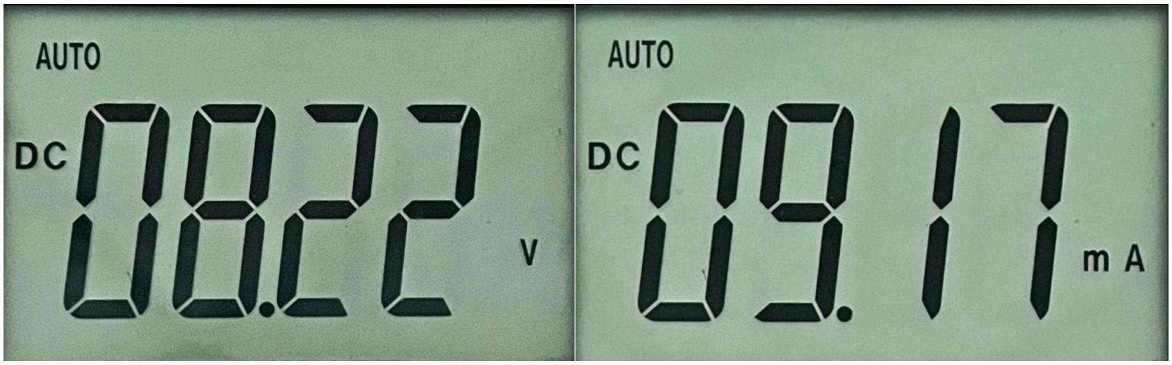


Figure 14: Q-point values of Q1

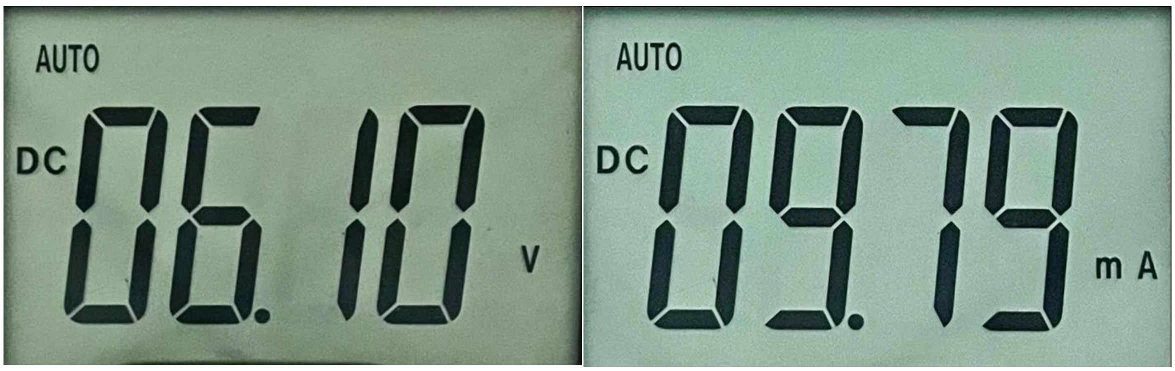


Figure 15: Q-point values of Q2

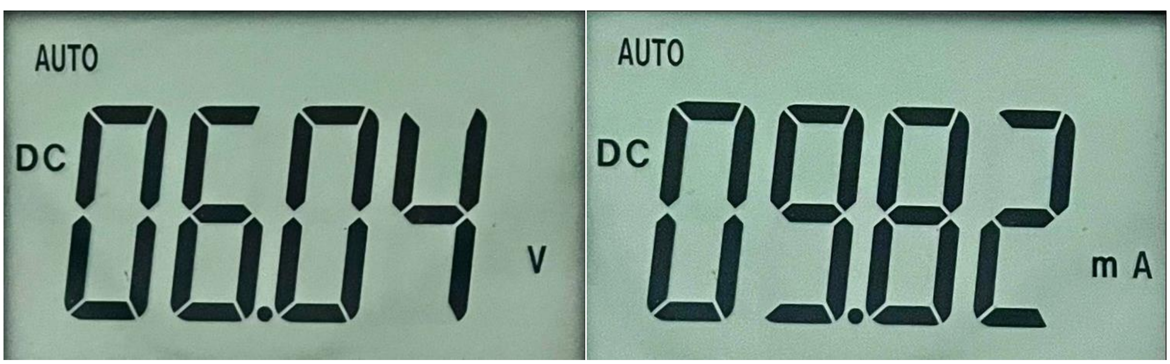


Figure 16: Q-point values of Q3

	THEORETICAL VALUE	EXPERIMENTAL VALUE	ERROR
I_C of Q1	9.22 mA	9.17 mA	0.65%
V_{CE} of Q1	8.06 V	8.22 V	1.98%
I_C of Q2	9.88 mA	9.79 mA	0.91%
V_{CE} of Q2	6.02 V	6.10 V	1.33%
I_C of Q3	9.93 mA	9.82 mA	0.50%
V_{CE} of Q3	5.97 V	6.04 V	1.17%

Table 2: Q-point values

B2) Voltage Gain at 0.1sinwt

In this part, when 236 mV pk-pk, i.e., approximately 0.1sinwt input, was applied, the output value obtained was measured as 1.20 V pk-pk, i.e., 0.6 V.

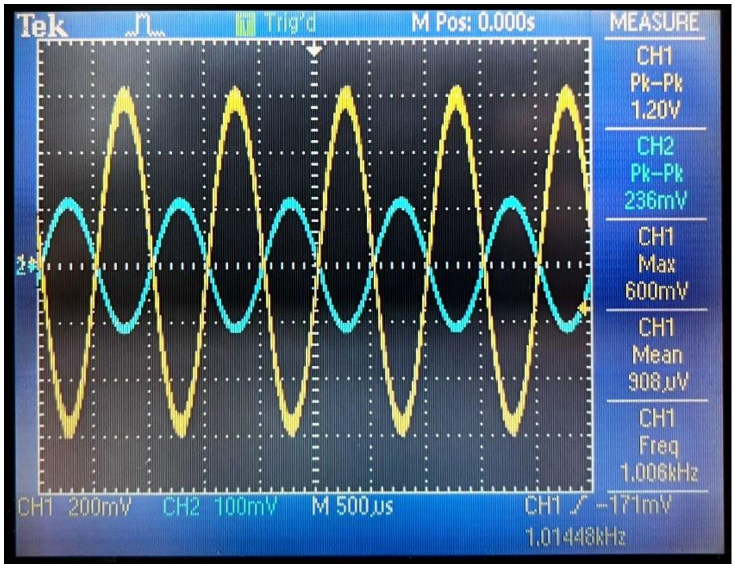


Figure 17: Output voltage at 0.1sinwt

When the gain is calculated with these two values, the result is -5.08. This value is very close to the desired value of -5.

B3) Voltage Gain and the Harmonic Content

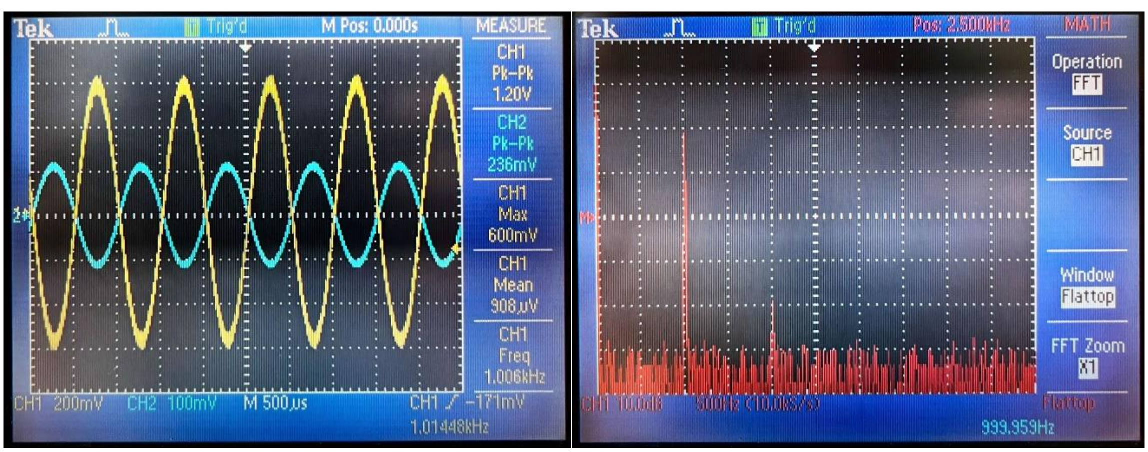


Figure 18: Output voltage and harmonic content at 0.1sinwt

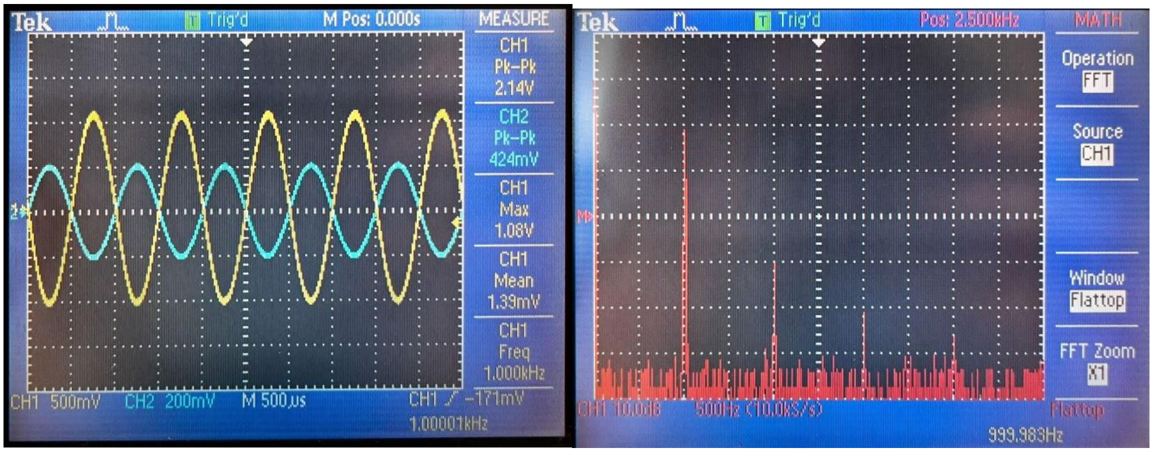


Figure 19: Output voltage and harmonic content at 0.2sinwt

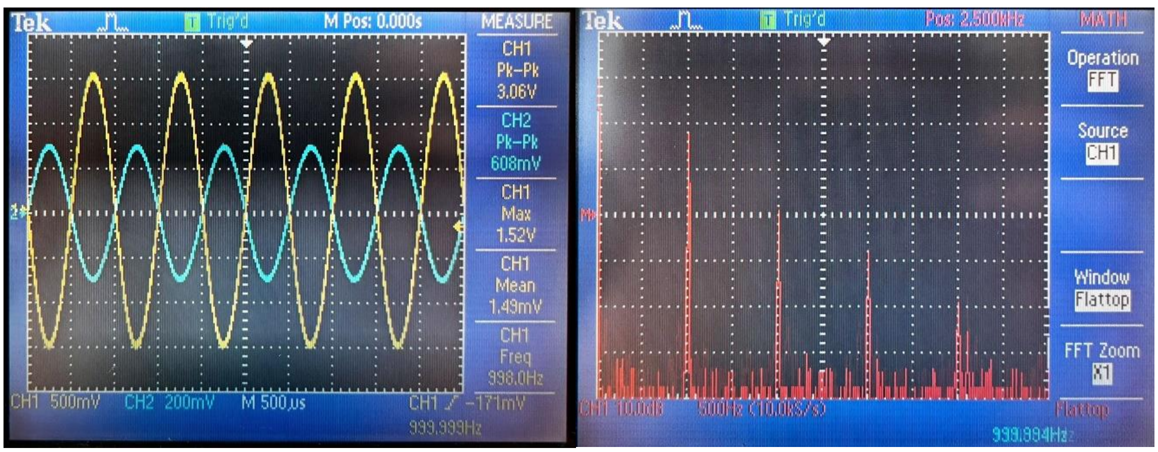


Figure 20: Output voltage and harmonic content at 0.3sinwt

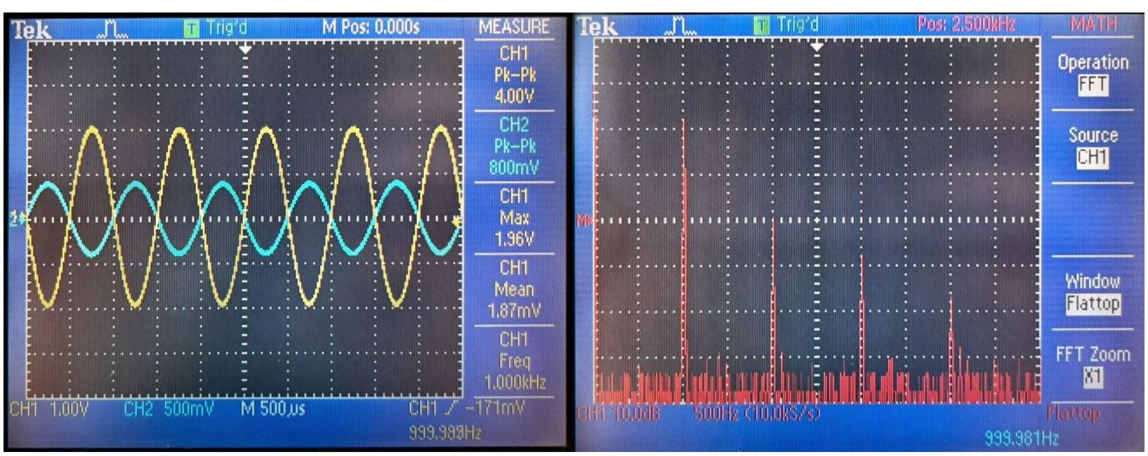


Figure 21: Output voltage and harmonic content at 0.4sinwt

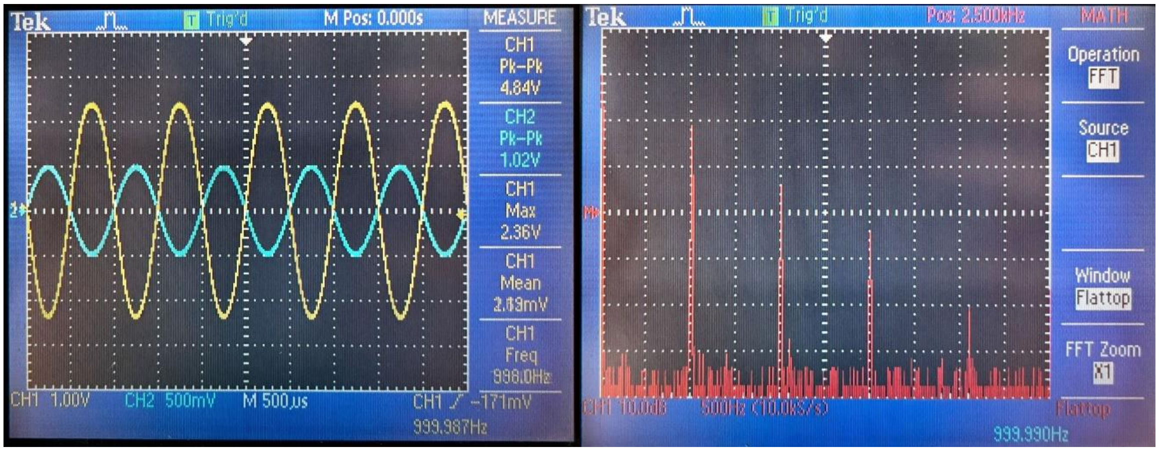


Figure 22: Output voltage and harmonic content at 0.5sinwt

	0.1sinwt	**0.2sinwt**	**0.3sinwt**	**0.4sinwt**	**0.5sinwt**
output	1.20 V	2.14 V	3.06 V	4.00 V	4.84 V
input	0.236 V	0.424 V	0.608 V	0.800 V	1.020 V
gain	-5.08	-5.05	-5.03	-5.00	-4.75

Table 3: Output, input, and gain at different voltages

As the input voltage increases, the gain increases minimally. After 0.4sinwt, the decrease in gain increases; this is because the output starts to be clipped. As for harmonic content, the Fourier series coefficient occurs as the input value increases because the output is clipped and becomes more like a periodic square wave. Harmonic content becomes increasingly distorted due to the distortion of the smooth sine wave.

B4) The Maximum Peak Input Without Clipping at the Output

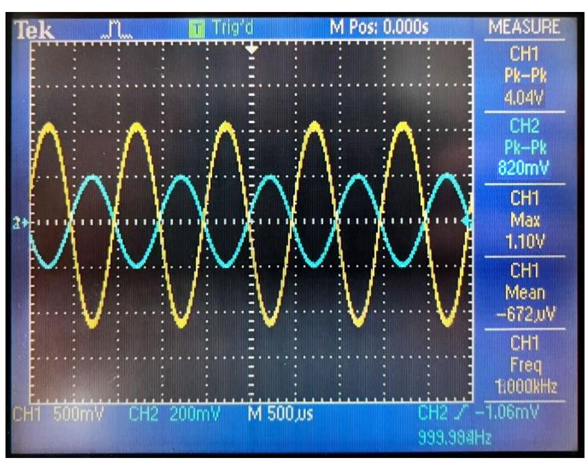


Figure 23: The maximum input without clipping at the output:

As seen from the image above, when the input is 0.41sinwt, the gain is -4.92; that is, the increase in gain increases after this value.

B5) Finding the f_L and f_H

In this part, there will be two different frequency values where 20 log (gain) is 3 dB below the maximum value. For the 20log (Vout/220 mV) value to be 14.25-3=11.25, the output value should be approximately 800 mV.

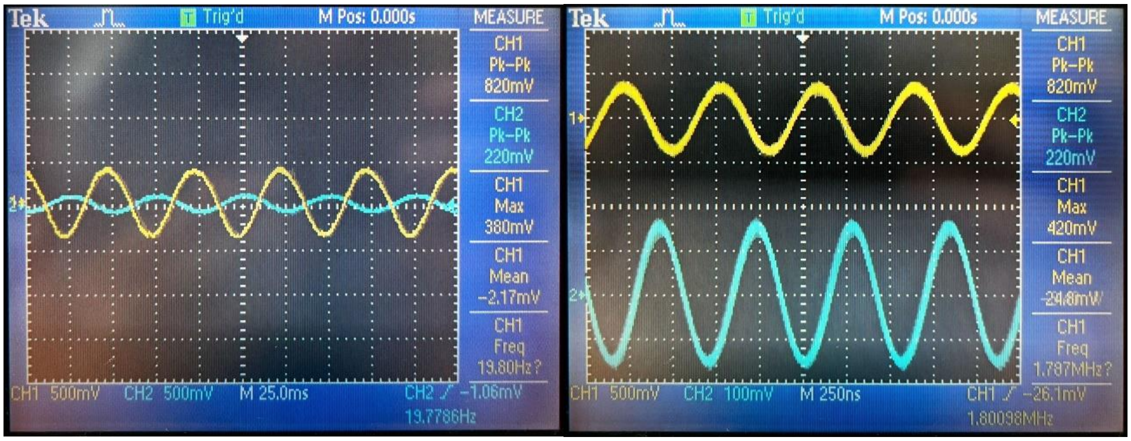


Figure 24: f_L and f_H values

As can be seen in the measurements above, the f_L value is approximately 20 Hz, while the f_H value is 1.8 MHz.

Conclusion

This lab aimed to familiarize BJTs and design a Two-stage BJT amplifier: A common emitter stage cascaded with a push-pull voltage buffer. First, DC and AC analysis was performed to determine the required resistor values , and by calculating gain, it was confirmed that the specifications were satisfied. Then -3dB low and high cutoff frequencies of the amplifier were determined. In the hardware section, the circuit was established with values closest to the selected resistor values. Firstly, Q-point value measurements were made only with DC input and compared with the values in the software section. Afterward, the gain calculation was made with 0.1sinwt input, and the desired gain value was obtained. After this, the input was increased at 0.1 intervals until the value of 0.5sinwt, and the gain and harmonic content changes were observed. The maximum input without clipping at the output value was determined, and finally -3dB low and high cutoff frequencies were measured. There were no significant difficulties during the lab. Some minor errors occurred due to the non-ideal BJT and diodes, imprecise component values, and the material quality or sensitivity of the oscilloscope, signal generator, multimeter, and breadboard. Thanks to this lab, the logic of BJTs and the logic of providing ON state were learned thanks to the diodes used with BJTs. Additionally, learning how to use a test source in LTSpice while measuring the input and output resistance of the amplifier will be helpful information for future labs.