İhsan Doğramacı Bilkent University

ELECTRICAL and ELECTRONICS ENGINEERING

Bilkent University
Department of Electrical and Electronics Engineering

EE-313 ELECTRONIC CIRCUIT DESIGN

LAB-3 FINAL REPORT

Single-Supply Push-pull Class-B Power Amplifier

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1 Introduction

This experiment focuses on designing and testing a single-supply Class-B push-pull amplifier using a +24V source. The goal is to achieve at least 0.95W output to a 33 load with 24 dB voltage gain.

In the preliminary stage, component values were calculated to meet the key specs: 150 Hz–15 kHz bandwidth, THD below -40 dB, under 500 mW quiescent power, and over 40 percent efficiency.

In the experimental part, the circuit is built using BC238, BC308, BD135, BD136 transistors and an LM358 op-amp. Measurements are taken to verify whether the design meets all specifications.

There are 5 specifications that must be specified:

1. The amplifier should deliver at least 0.95W power to a 33 ohm resistance (16Vpp to a 33 ohm power resistor) at 1KHz with the chosen gain value.

2. The harmonics (the highest is possibly the third harmonic) at the 0.95W output power level. should be at least 40 dB lower than the fundamental signal at 1 KHz.

3. The power consumption at quiescent conditions should be less than 500mW.

4. The amplifier's efficiency (output power/total supply power) should be at least 40 percent at max power output (0.95W) at 1KHz.

5. The 3dB bandwidth of the amplifier should be at least 150Hz to 15KHz.

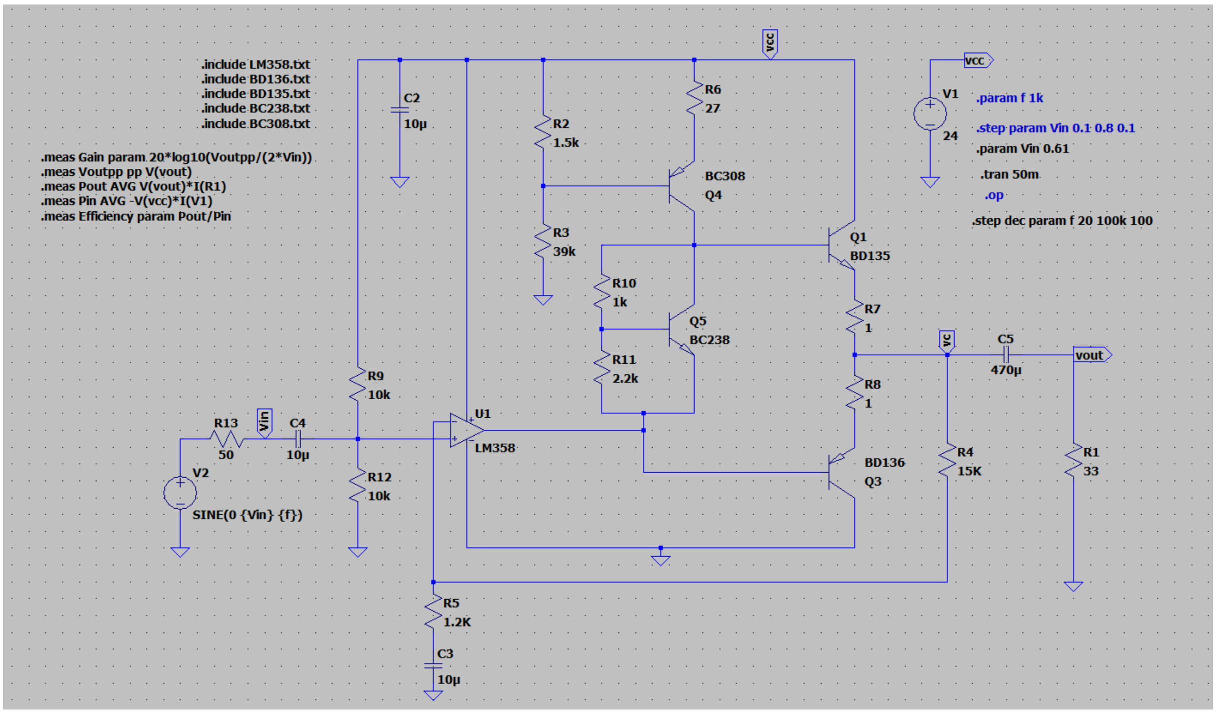

Figure 1: Circuit

PRELIMINARY WORK

$Vout$ values between 0.1V and 0.8V with 0.1 step size.

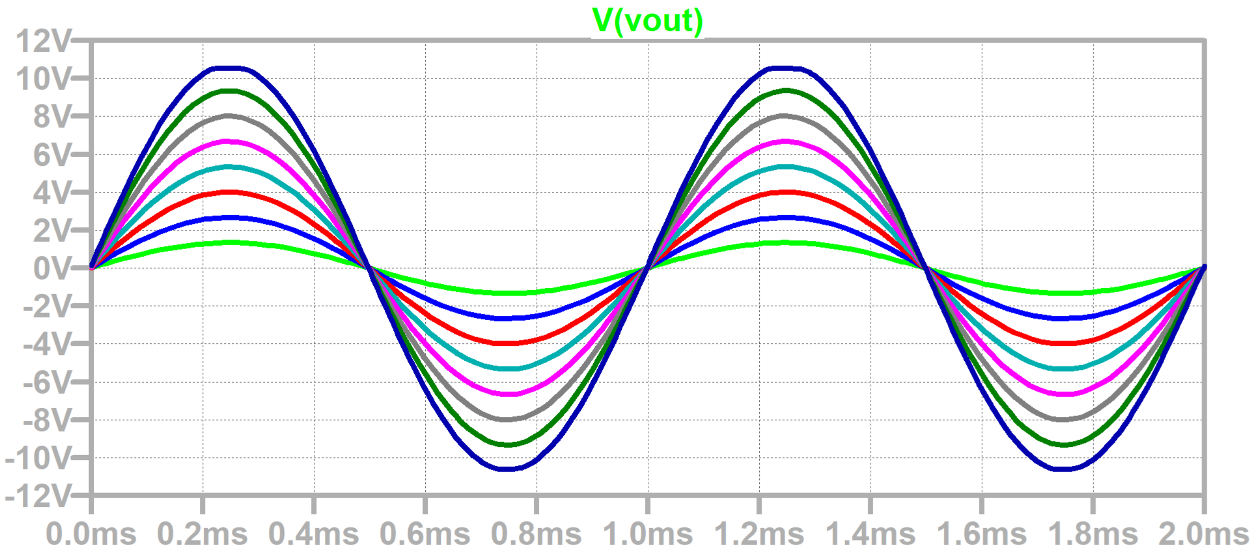

Figure 2: $Vout$

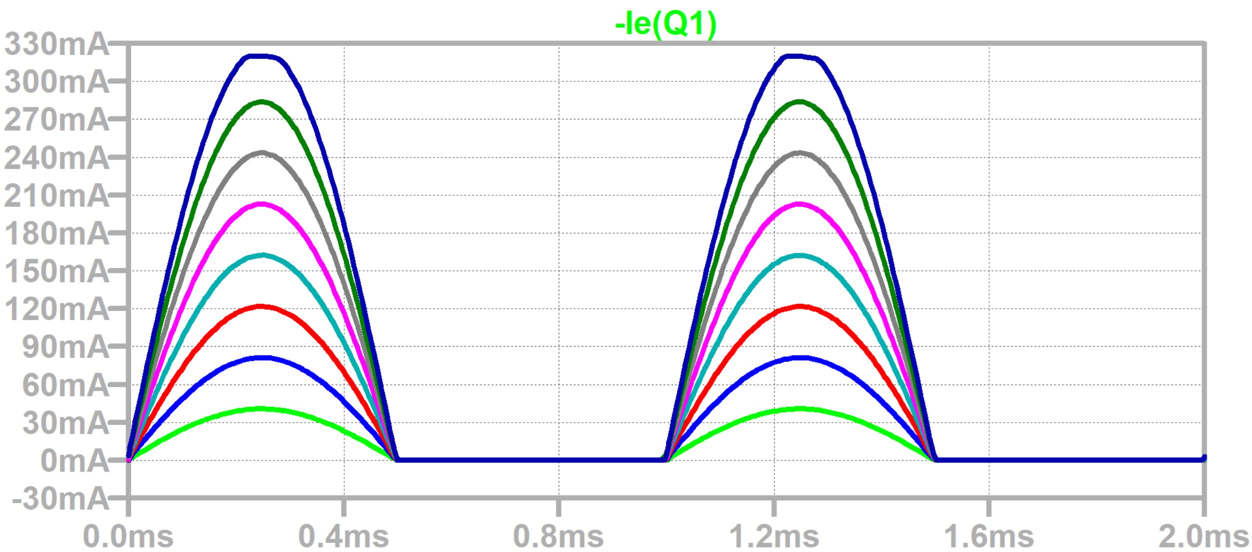

Figure 3: Emitter current for Q1

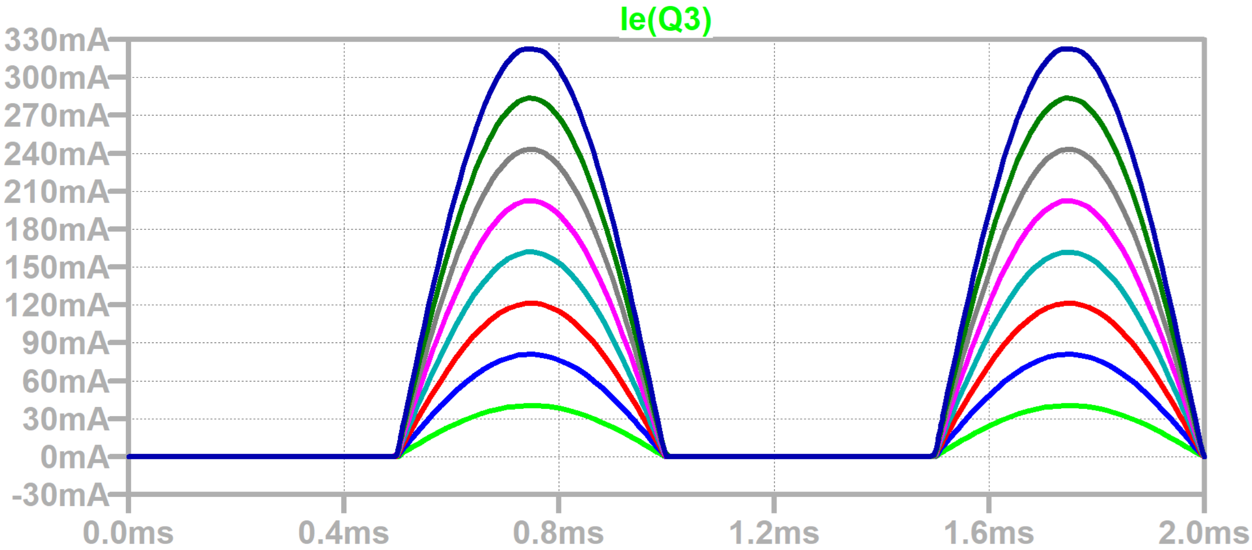

Figure 4: Emitter current for Q3

This is the full version of Class B amplifier:

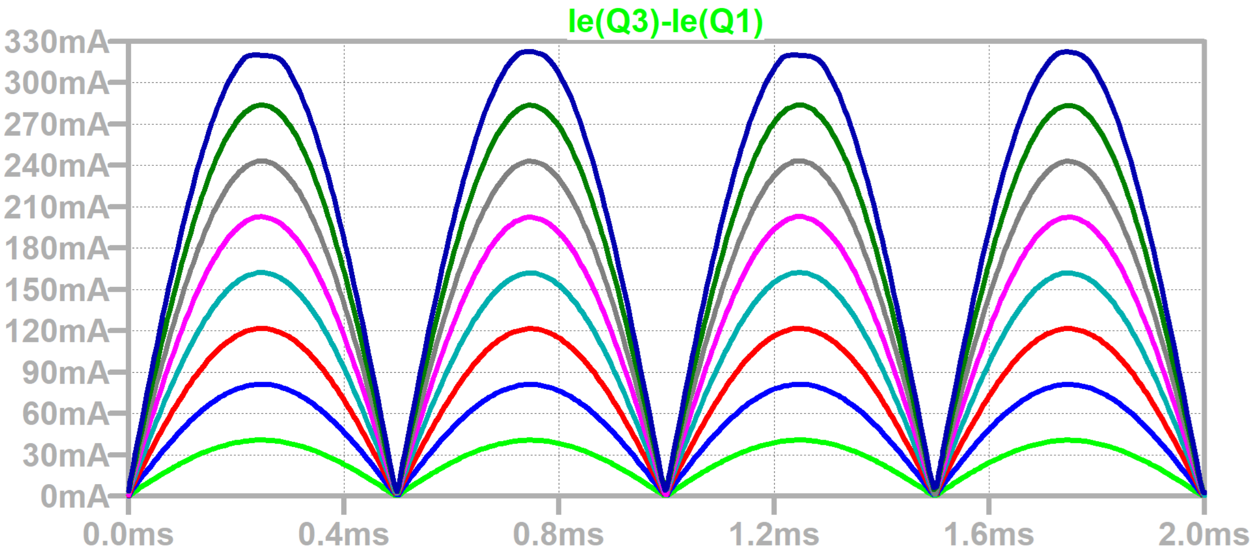

Figure 5: Class B Amplifier

Measurements

These are measured between Vin=0.1 and Vin=0.8

```
Measurement: gain
  step         20*log10(voutpp/(2*vin))
     1         22.5116
     2         22.5091
     3         22.5109
     4         22.5125
     5         22.5123
     6         22.5115
     7         22.513
     8         22.4272

Measurement: voutpp
  step         PP(v(vout))        FROM        TO
     1         2.67061         0         0.002
     2         5.3397         0         0.002
     3         8.01113         0         0.002
     4         10.6836         0         0.002
     5         13.3541         0         0.002
     6         16.0235         0         0.002
     7         18.6973         0         0.002
     8         21.1583         0         0.002

Measurement: pout
  step         AVG(v(vout)*i(r1))         FROM        TO
     1         0.0269802         0         0.002
     2         0.107921         0         0.002
     3         0.24282         0         0.002
     4         0.431683         0         0.002
     5         0.674511         0         0.002
     6         0.971632         0         0.002
     7         1.32267         0         0.002
     8         1.72293         0         0.002

Measurement: pin
  step         AVG(-v(vcc)*i(v1))         FROM        TO
     1         0.531177         0         0.002
     2         0.838648         0         0.002
     3         1.14581         0         0.002
     4         1.45284         0         0.002
     5         1.75972         0         0.002
     6         2.06608         0         0.002
     7         2.37288         0         0.002
     8         2.67563         0         0.002

Measurement: efficiency
  step         pout/pin
     1         0.0507932
     2         0.128685
     3         0.211921
     4         0.297131
     5         0.383305
     6         0.470277
     7         0.557413
     8         0.643934
```

---

2 Specifications

1st Specification

The amplifier should deliver at least 0.95W power to a 33 ohm resistance (16Vpp to a 33 ohm power resistor) at 1KHz with the chosen gain value.

$V_{in} = 0.61V$ is used for this specification. More possibly, we can also use 0.6V
The output measurements are those when $V_{in} = 0.61V$:

```
gain: 20*log10(voutpp/(2*vin))=22.4966
voutpp: PP(v(vout))=16.0227 FROM 0 TO 0.004
pout: AVG(v(vout)*i(r1))=0.970849 FROM 0 TO 0.004
pin: AVG(-v(vcc)*i(v1))=2.06696 FROM 0 TO 0.004
efficiency: pout/pin=0.469699
```

As shown in the analysis, *pout* is at least 0.95W when $V_{in} = 0.61V$, so we should use this value while performing the analysis in the lab. Moreover, any value bigger than 0.6V can also be acceptable.

2nd Specification

The harmonics (the highest is possibly the third harmonic) at the 0.95W output power level should be at least 40 dB lower than the fundamental signal at 1 KHz.

For this specification, we should compare the power of two points, between 1KHz and highest point other thant 1kHz.

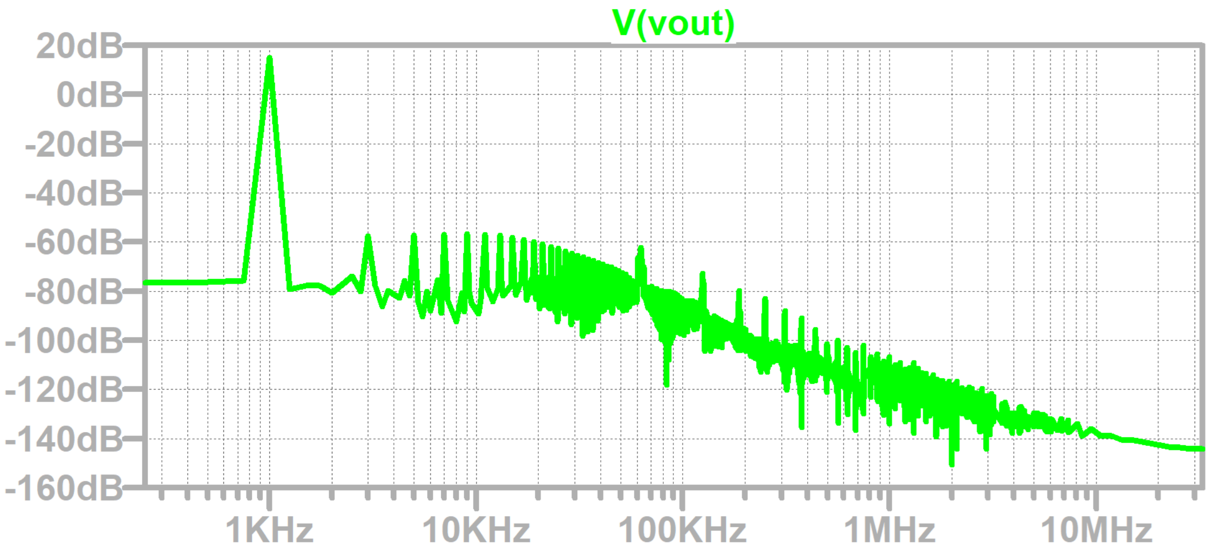

Figure 6: 2nd Specification

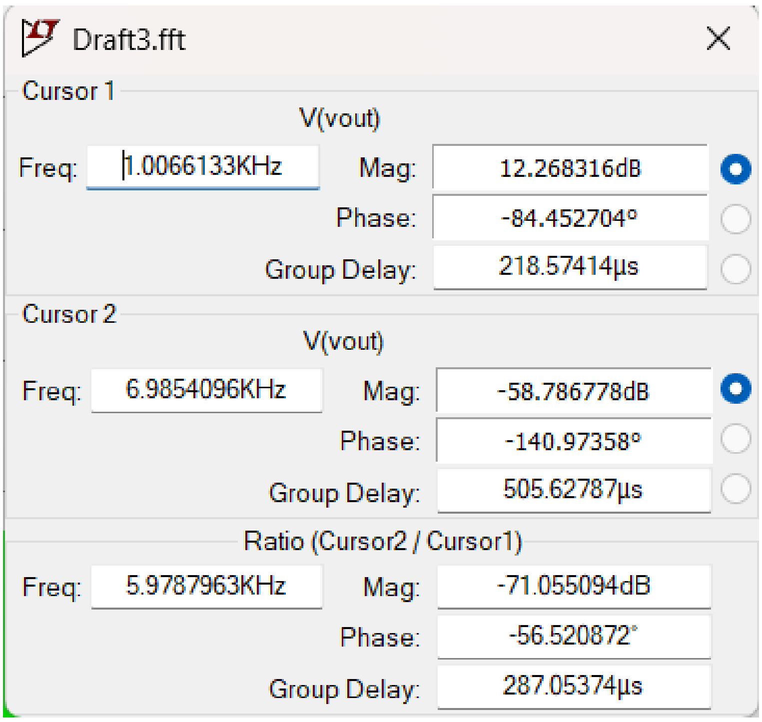

Figure 7: 2nd Specification

As shown in the analysis, the harmonics at the 0.95W output power level ($V_{in} = 0.61V$) is at least 70 dB lower than the fundamental signal at 1 KHz.

3rd Specification

The power consumption at quiescent conditions should be less than 500mW
For this specification, we should look at power consumption at quiescent conditions and table below shows this.

```
gain: 20*log10(voutpp/(2*vin))=inf
voutpp: PP(v(vout))=2.51742e-09 FROM 0 TO 0.004
pout: AVG(v(vout)*i(r1))=6.30467e-20 FROM 0 TO 0.004
pin: AVG(-v(vcc)*i(v1))=0.224693 FROM 0 TO 0.004
efficiency: pout/pin=2.8059e-19
```

As shown in the analysis, *pout* shows the power dissipated by load resistance at quiescent condition and this is by far different than 500mW.

4th Specification

The amplifier's efficiency (output power/total supply power) should be at least 40 percent at max power output (0.95W) at 1KHz.
For this specification, we should look at the efficiency when $V_{in} = 0.61V$

```
gain: 20*log10(voutpp/(2*vin))=22.4952
voutpp: PP(v(vout))=16.26 FROM 0 TO 0.004
pout: AVG(v(vout)*i(r1))=1.00013 FROM 0 TO 0.004
pin: AVG(-v(vcc)*i(v1))=2.09477 FROM 0 TO 0.004
efficiency: pout/pin=0.477439
```

As shown in the analysis, $efficiency$ shows the amplifier's efficiency and this is 47 percent, higher than 40 percent.

5th Specification

The 3dB bandwidth of the amplifier should be at least 150Hz to 15KHz.

For this specification, we should look at the gain graphic.

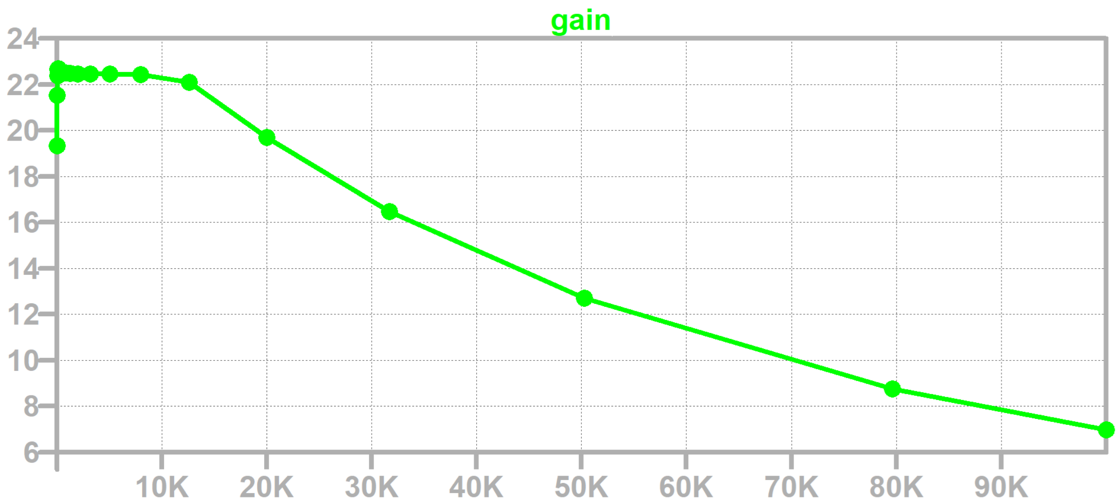

Figure 8: 5th Specification

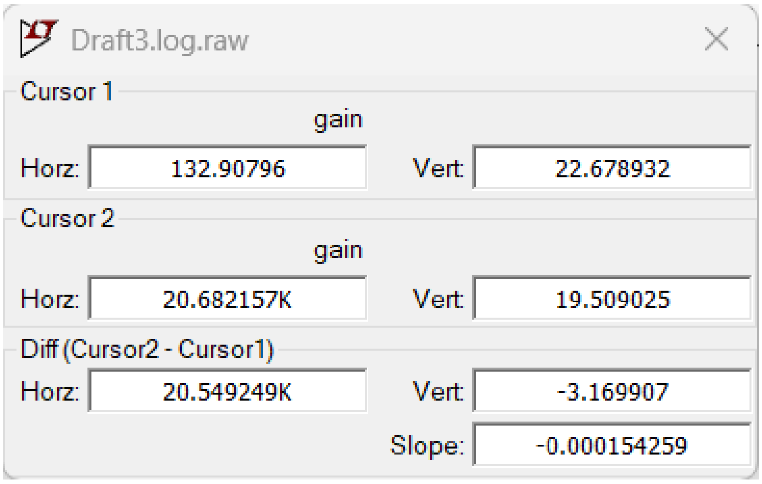

Figure 9: 5th Specification

As shown in the graph, 3dB bandwidth of the amplifier should be at least 150Hz to 15KHz.

EXPERIMENTAL WORK

This is the circuit implementation. It was a bit hard to implement because there were many components.

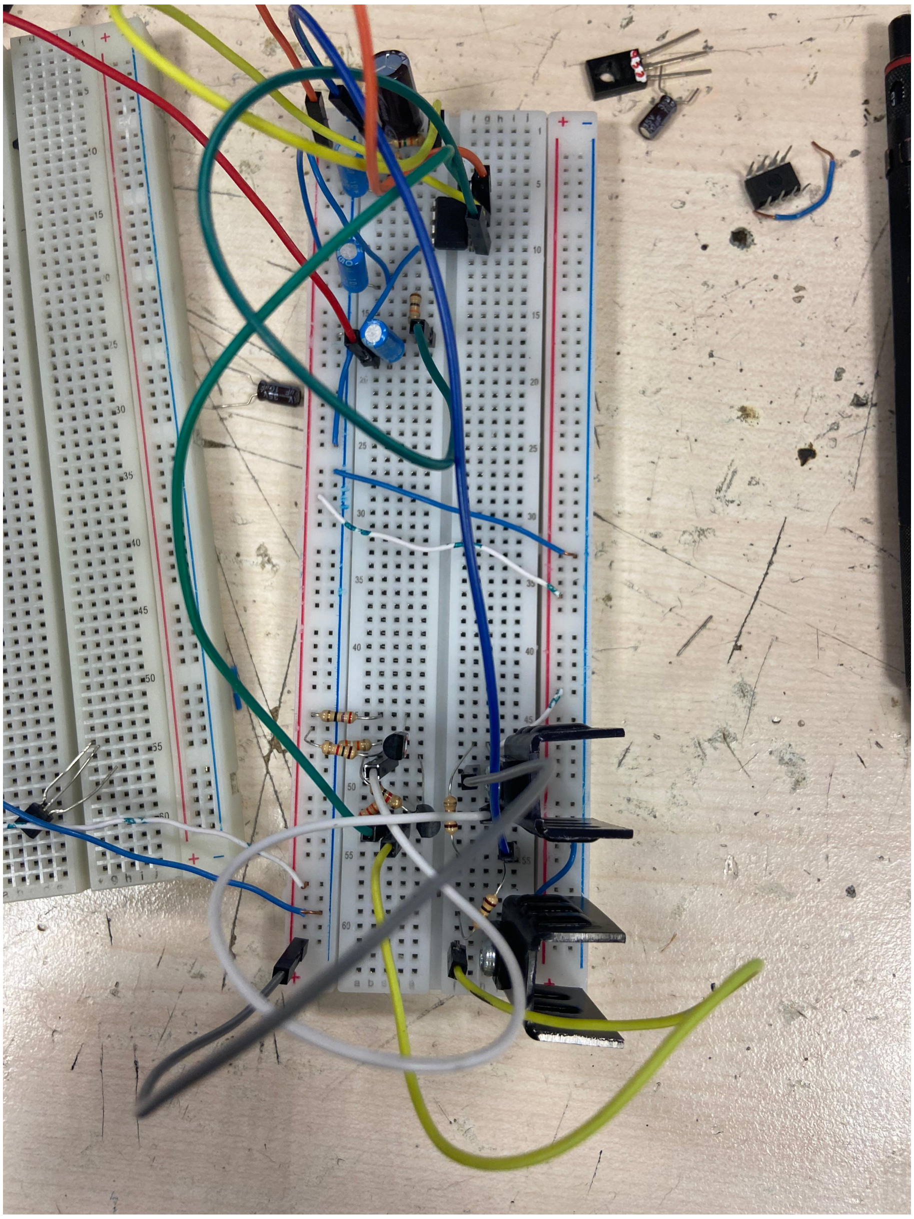

Figure 10: Circuit Implementation

Specifications

1st Specification

The amplifier should deliver at least 0.95W power to a 33 ohm resistance (16Vpp to a 33 ohm power resistor) at 1KHz with the chosen gain value.

In experimental part, settings of the signal generator are $V_{in} = 0.60V$ and 1kHz for 16 Vpp output.

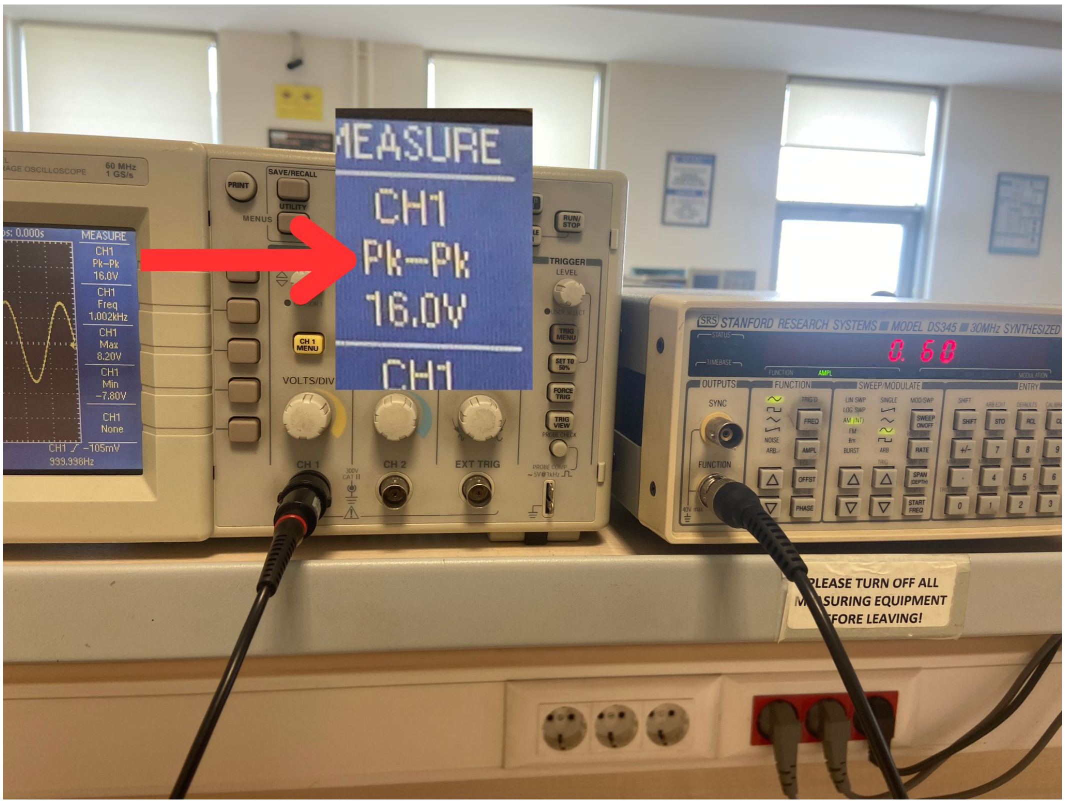

Figure 11: Experimental Settings

Output oscilloscope figure when $V_{in} = 0.60V$:

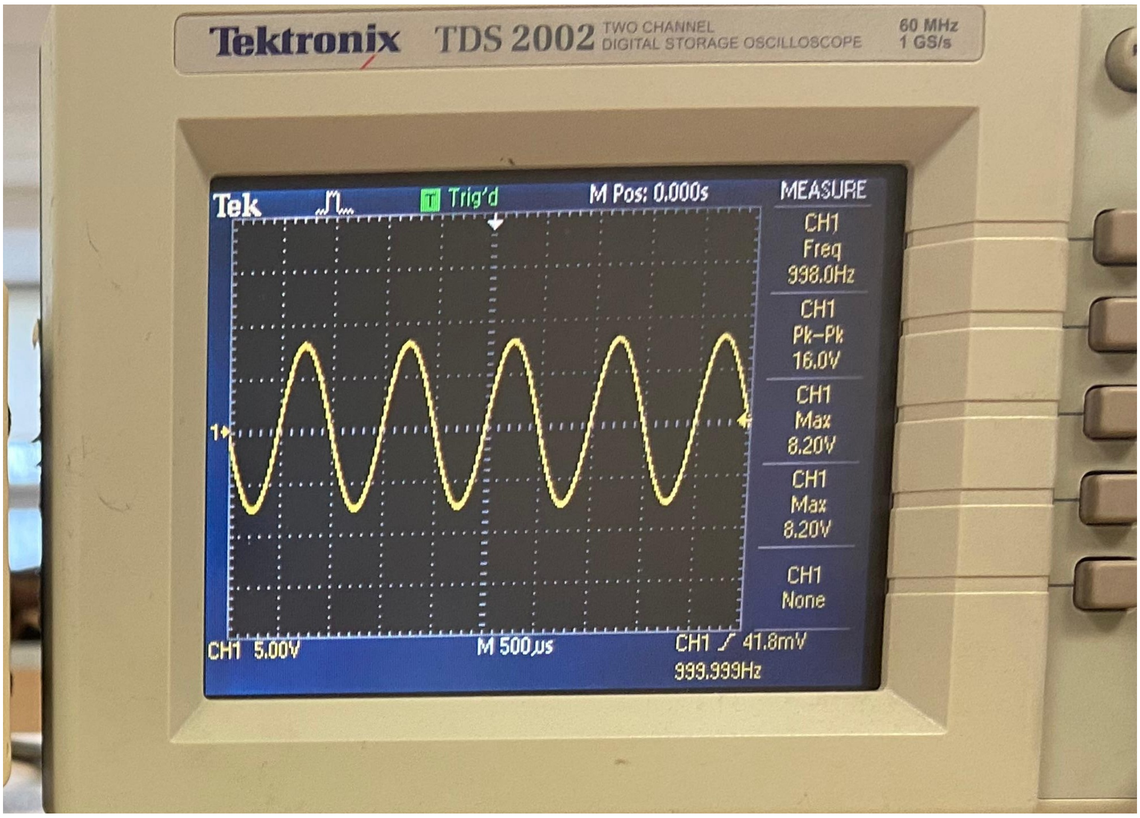

Figure 12: V_{out}

As shown in the figures, $V_{out_{pp}} = 16V$ when $V_{in} = 0.60V$.

2nd Specification

The harmonics (the highest is possibly the third harmonic) at the 0.95W output power level should be at least 40 dB lower than the fundamental signal at 1 KHz.

For this specification, we should set oscilloscope to the FFT mode.

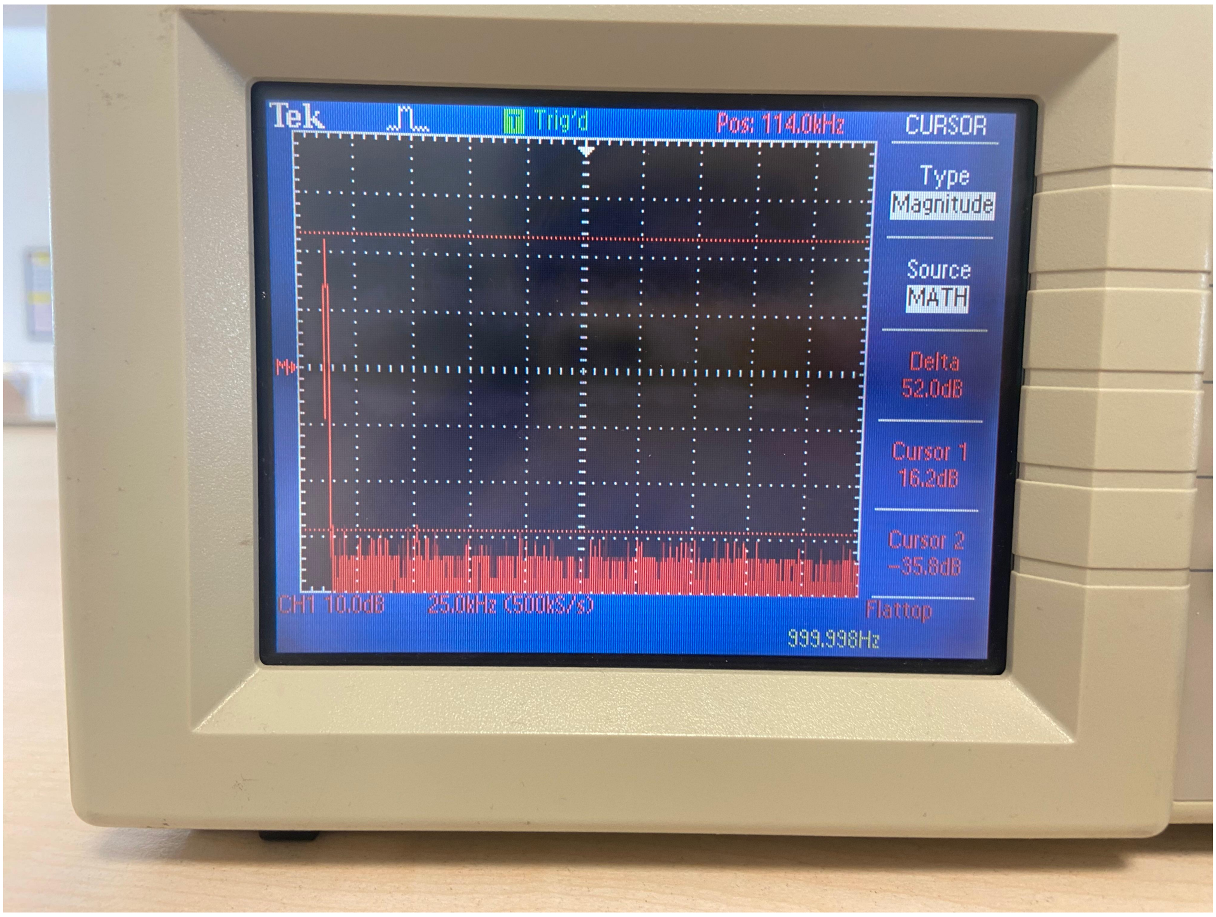

Figure 13: 2nd Specification

As shown in the figure, there is a difference of 52 dB, which is very acceptable.

3rd Specification

The power consumption at quiescent conditions should be less than 500mW

For this specification, we should look at power consumption when the signal generator does not work.

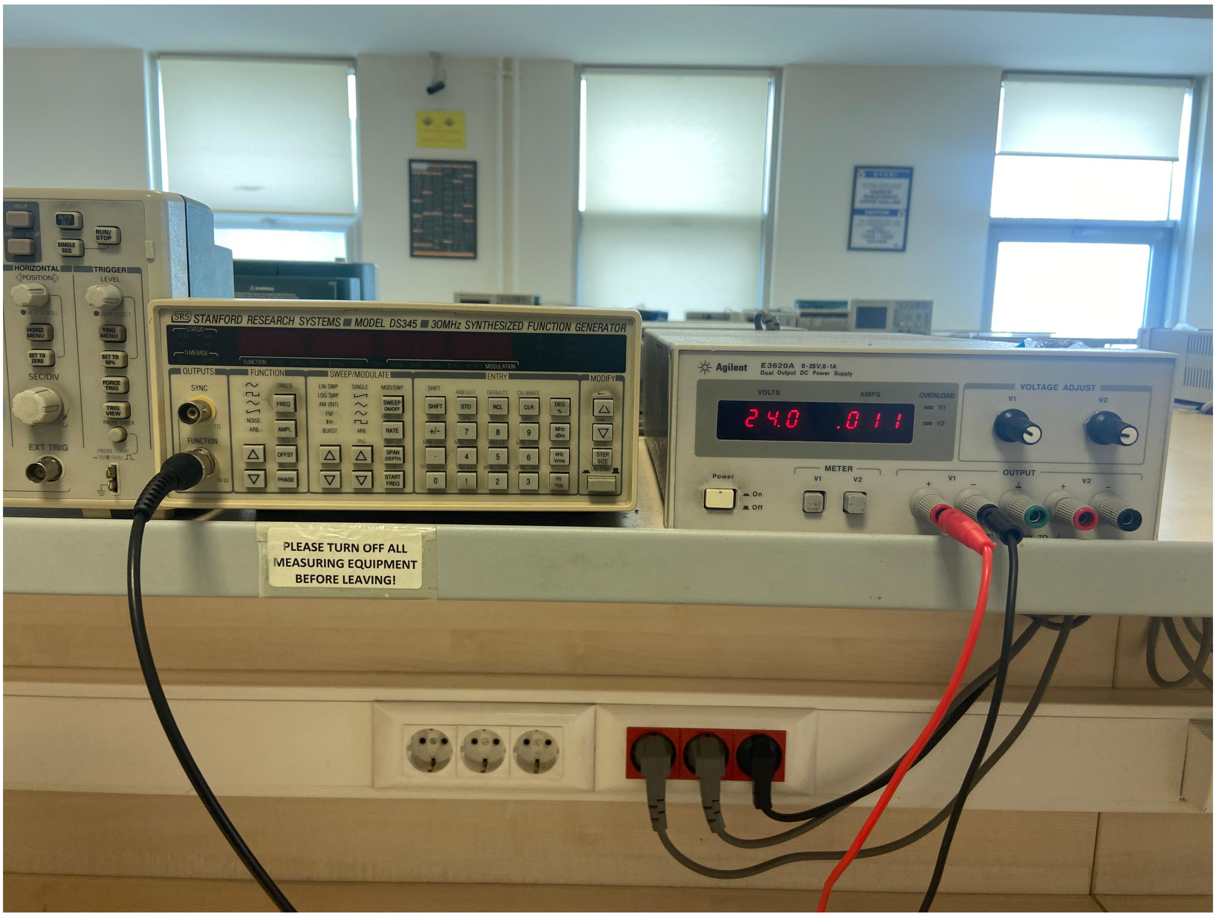

Figure 14: 3rd Specification

The formula to calculate electrical power (P) given voltage (V) and current (I) is:

$$P = V \times I$$

Given the values:

- Voltage (V) = 24
- Current (I) = 0.011

We can calculate the power as follows:

$$P = V \times I$$
$$P = 24 \times 0.011$$
$$P = 0.264$$

So, the calculated power is 0.264W and this is less than 500mW.

4th Specification

The amplifier's efficiency (output power/total supply power) should be at least 40 percent at max power output (0.95W) at 1KHz.
For this specification, we should look at the efficiency when $V_{in} = 0.60V$. We know $P_{out} = 0.95W$. We should look at P_{in}.

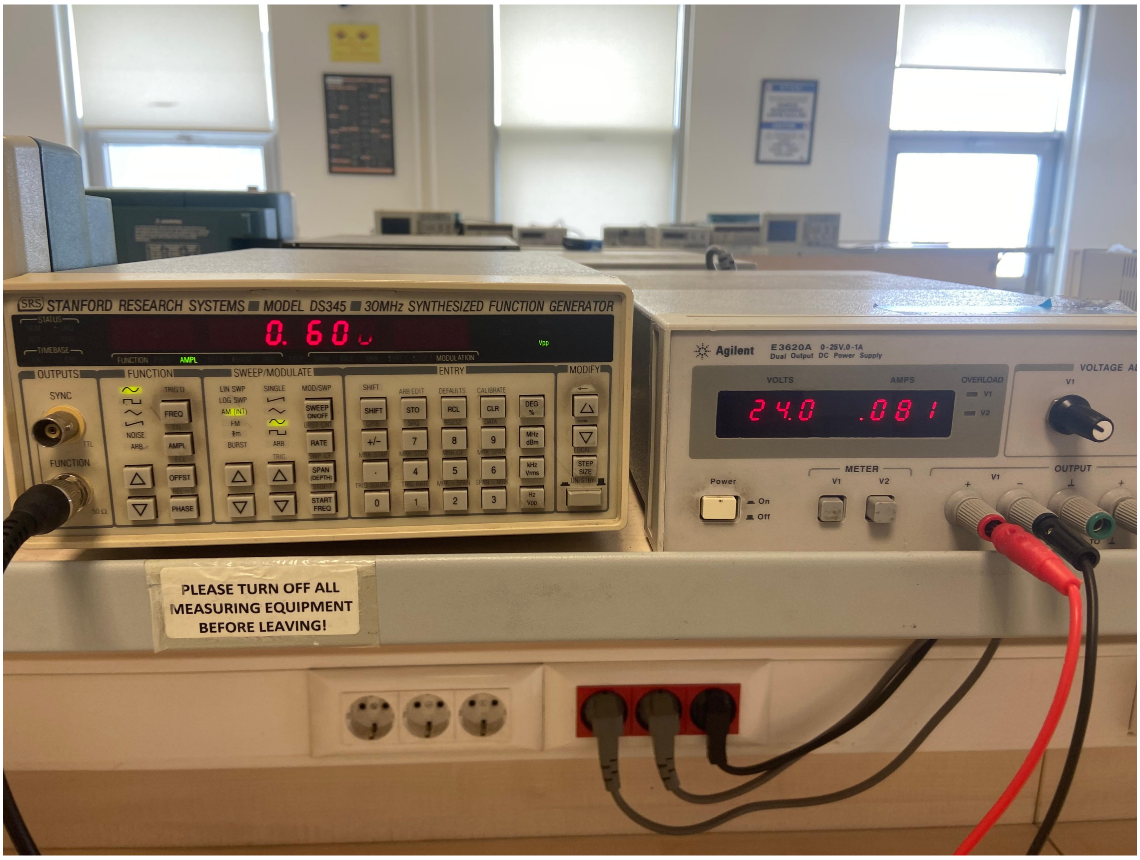

Figure 15: 4th Specification

As shown in the figure, $I_{in} = 0.081A$.
Given the specific values:

- Voltage (V) = 24
- Current (I) = 0.081

We calculate the power as follows:

$$P = V \times I$$
$$P = 24 \times 0.081$$
$$P = 1.944$$

$$\frac{P_{\text{out}}}{P_{\text{in}}} \times 100\% = \frac{0.95}{1.944} \times 100\% =$$

$$= 48.86 \quad \text{(approximately)}$$

As a result, 48 percent is very acceptable.

5th Specification

The 3dB bandwidth of the amplifier should be at least 150Hz to 15KHz.

For this specification, we should look at the gain graphic and for gain graphic we need to look at some frequency values.

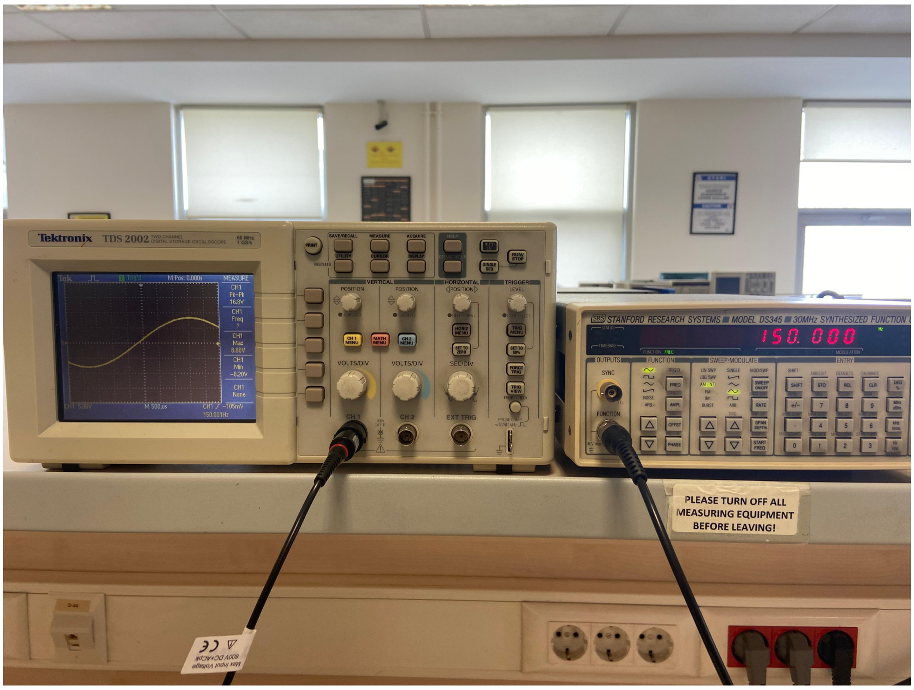

Figure 16: 150 Hz: $V = 16.8V$.

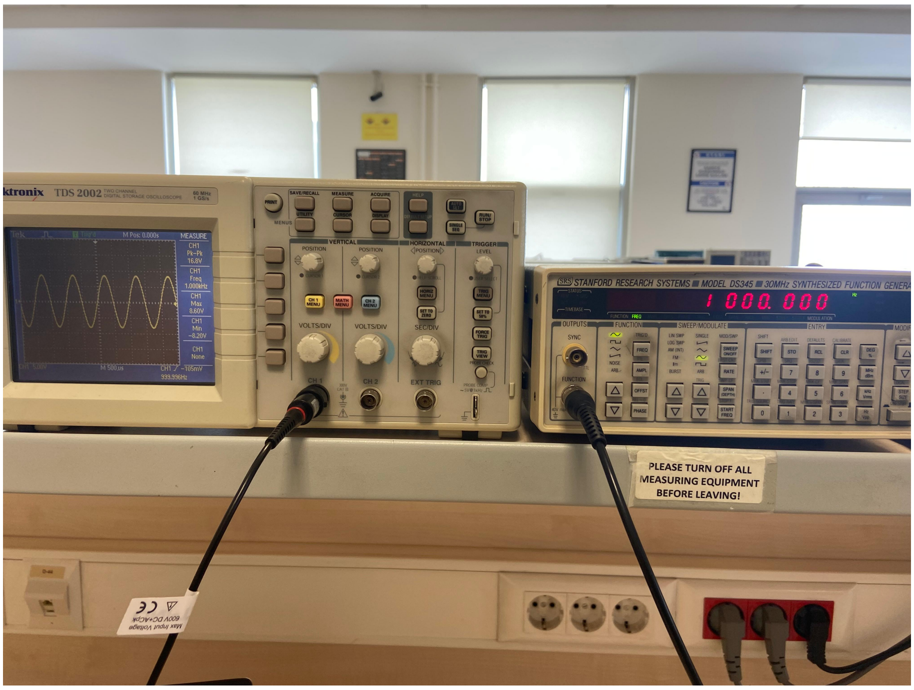

Figure 17: 1 kHz: $V = 16.8V$

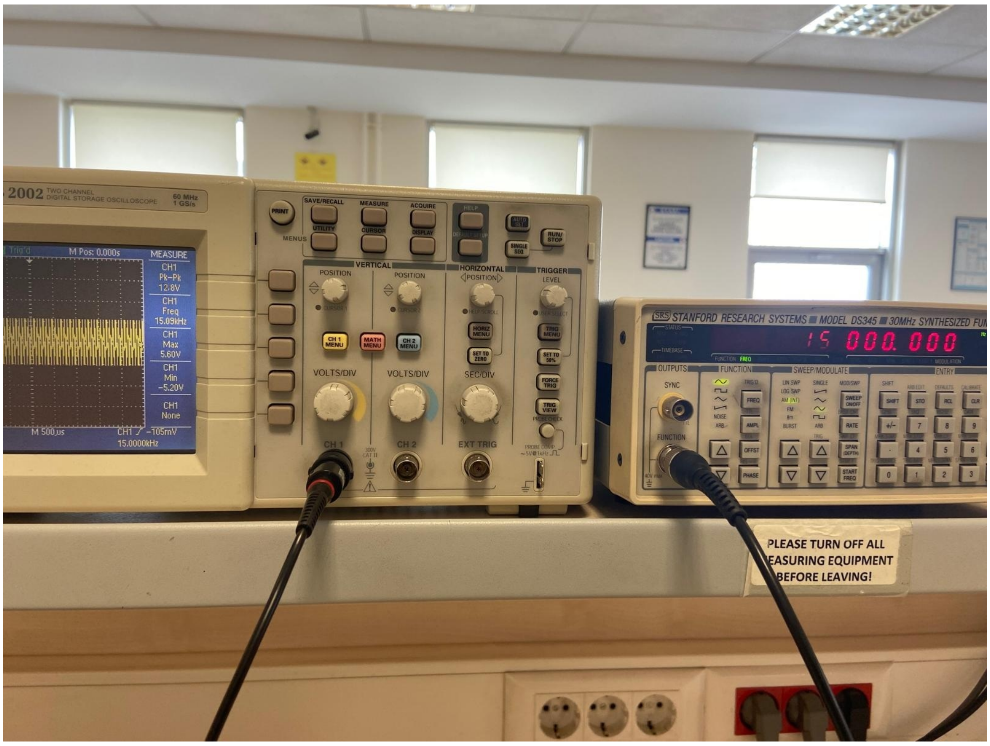

Figure 18: 15k: $V = 12.8V$

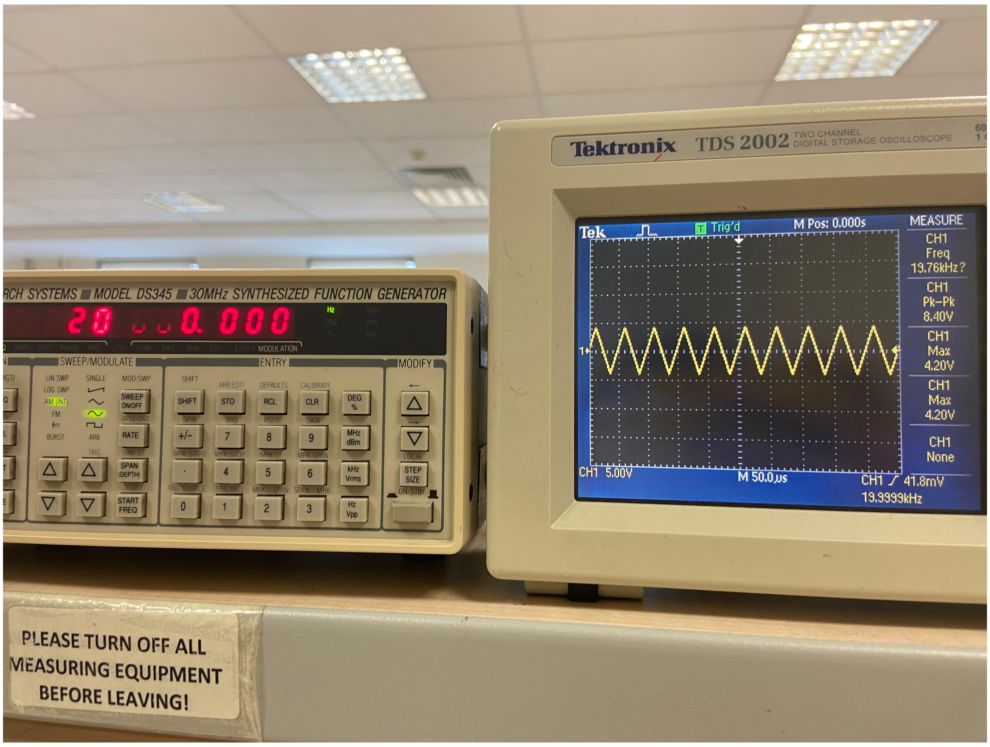

Figure 19: 20k: $V = 8.4V$

As shown in the graph, 3dB bandwidth of the amplifier is at least 150Hz to 15KHz.

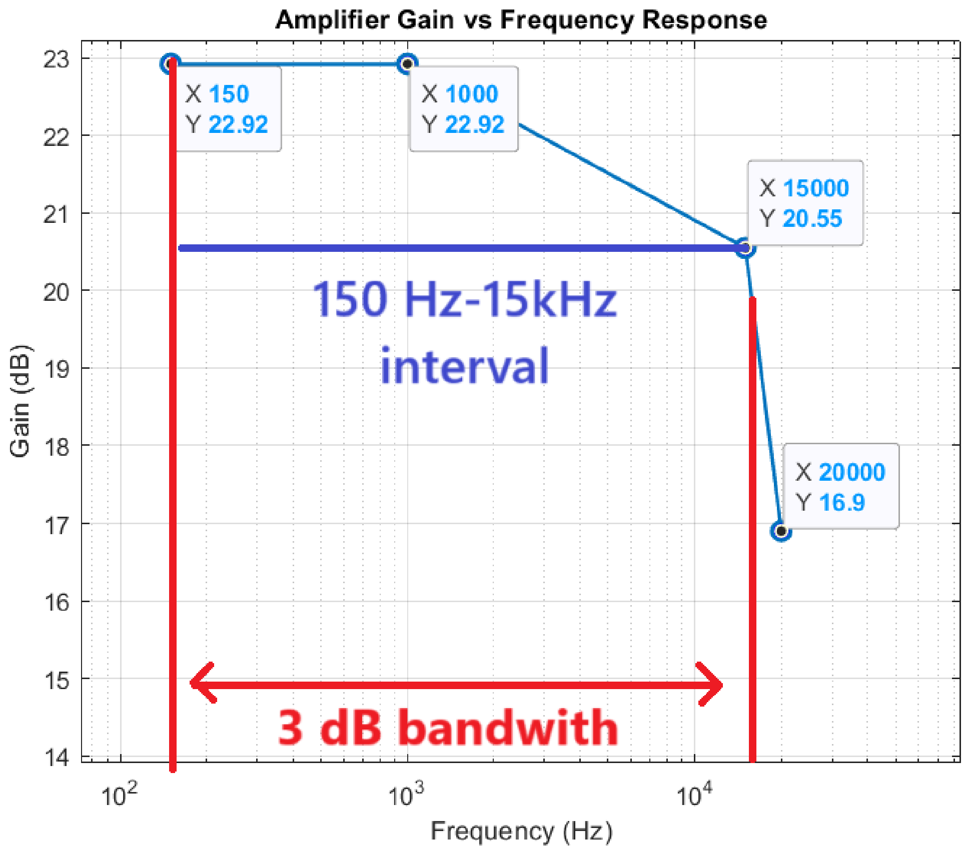

Figure 20: Bandwidth

Efficiency graph

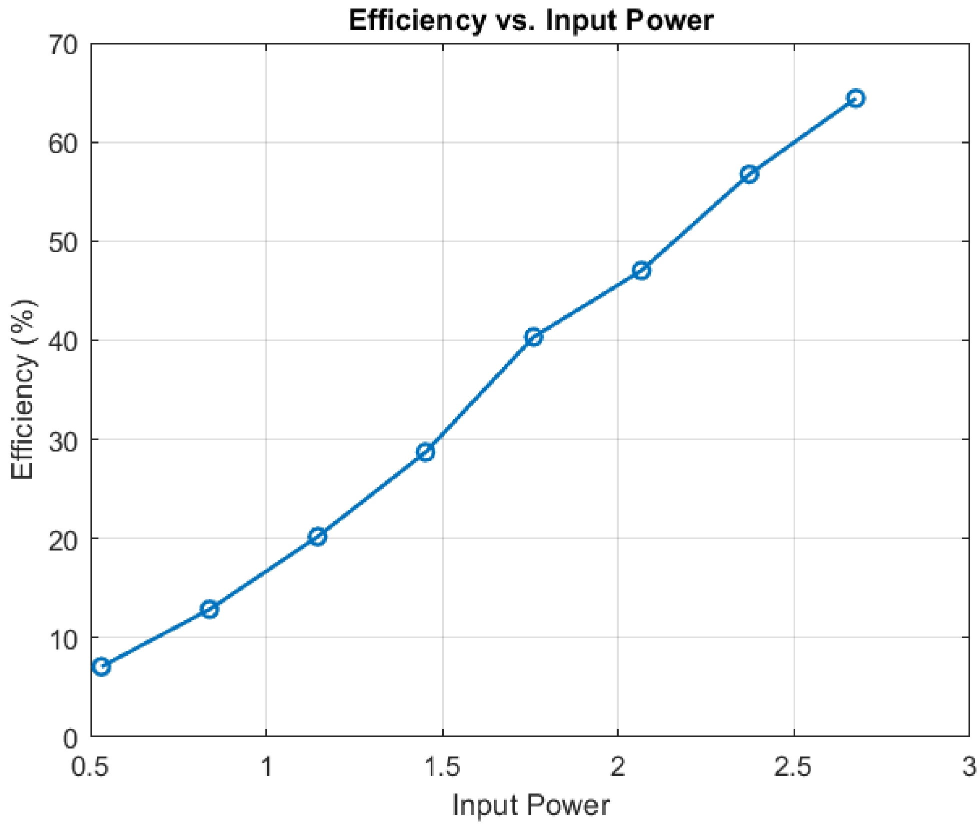

Figure 21: Efficiency

3 Conclusion

In this lab, we built and tested the Class-B push-pull amplifier. The experimental part showed that building the circuit was quite difficult because it had many components. We faced challenges during the setup, including burning several transistors, which reminded us of the practical difficulties in electronics.

Despite these difficulties, tests and measurements confirmed that our amplifier worked as planned. It successfully met all the required specifications, including delivering over 0.95W power, keeping harmonic distortion low, consuming less than 500mW when idle, achieving over 40 percent efficiency, and operating correctly within the 150Hz to 15kHz bandwidth. This practical work really helped to understand how to design amplifier circuits and how they amplify signals effectively.