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# EE313-Electronic Circuit Design

## Lab3-Preliminary and Experimental Work

### Push-pull Class-B Power Amplifier

## Preliminary Work

In this lab, the design and implementation of a complementary push-pull Class-B power amplifier have been undertaken. This amplifier aims to deliver a minimum of 2.25W to an 8.2Ω resistive load while operating within specified voltage and frequency ranges. Through careful consideration of component selection, circuit configuration, and performance criteria, the objective is to achieve not only the desired power output but also to ensure harmonic distortion remains well below acceptable thresholds, power consumption is minimized under quiescent conditions, and overall efficiency is optimized across the operational range.

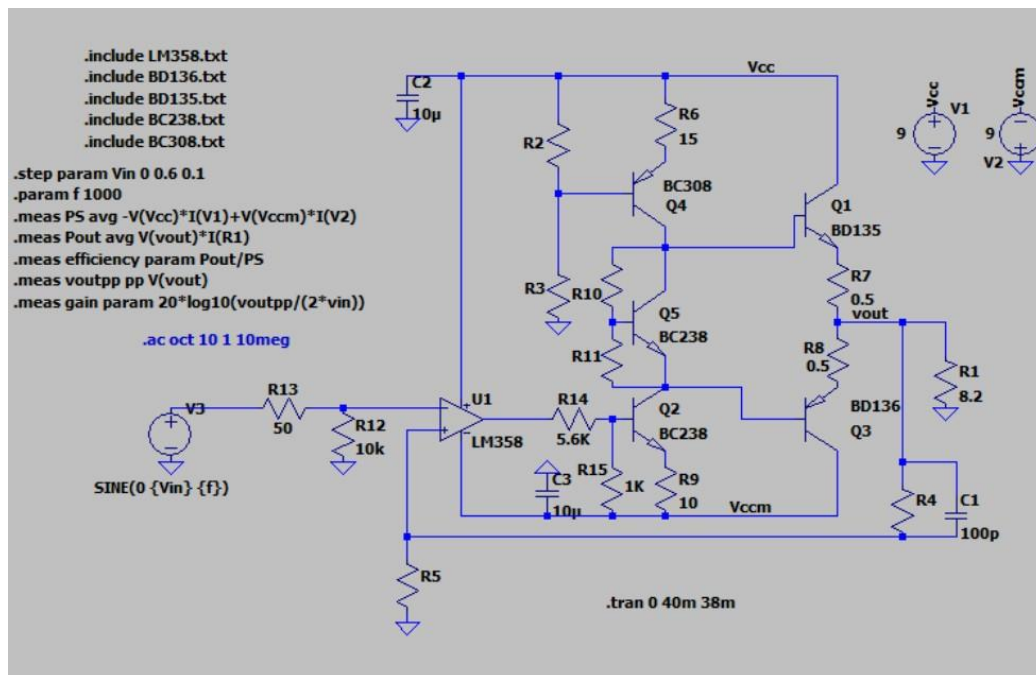


Figure 1: The main circuit where we need to find the appropriate values

First I checked whether I had a stability problem in my circuit, I removed the feedback loop and the OPAMP.

The DC offset voltage of the input voltage should be carefully adjusted (by trial and error) to keep the quiescent output voltage at zero. The input voltage source is now substituting the output of the opamp and now, we are acting like feedback. We are given a circuit below:

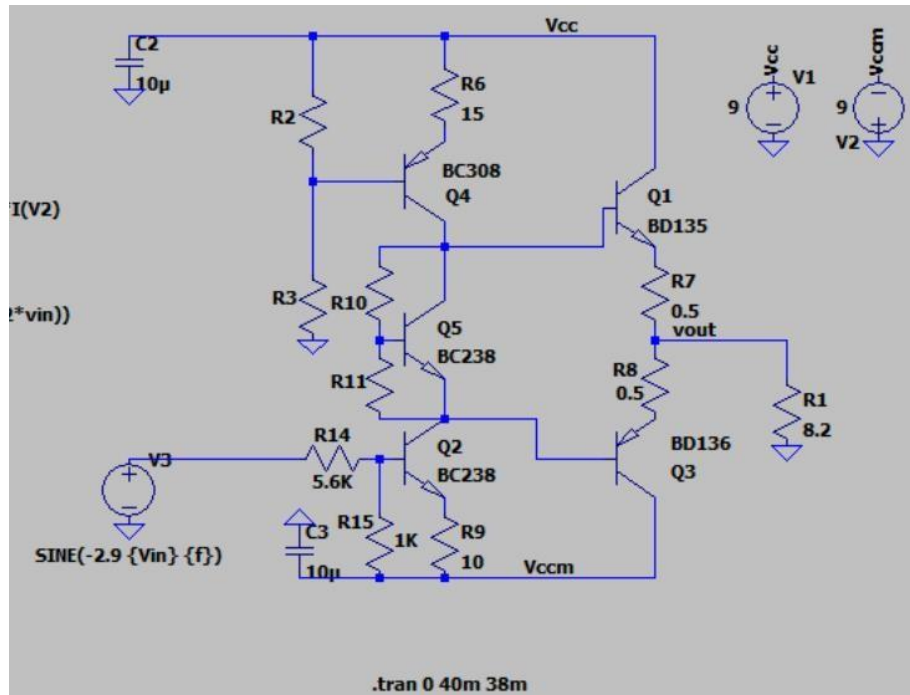


Figure 2: Circuit for solving crossover distortion

Checking the output behavior of this circuit we decided the R10 and R11 values. If we choose R10 too low, we get a crossover distortion. But with the proper value of R10 the voltage transition should be softer. And also from the lab manual we know, R10 and R11 needs to have the relation:

$$V_{CE} \approx \left(1 + \frac{R_{10}}{R_{11}}\right) V_{BE} \quad (\text{eqn. 1})$$

Also, the VCE of Q5 should be about twice that of VBE, so that we conclude R10 and R11 has to be very close to each other! I start with taking them both 4.7k. However, when we take them equal I got my Ps very high, not satisfying the 3rd specification (quiescent condition power consumption). But when I lower R10 a little bit but while staying in the not distortion region, I got lower Ps value only in the quiescent condition and at the same time I got more accurate emitter current (Figure 3 and 4) for Q1 and Q3 (which are BD135 npn and BD136 pnp power transistors). (Q4 acts like a current source).

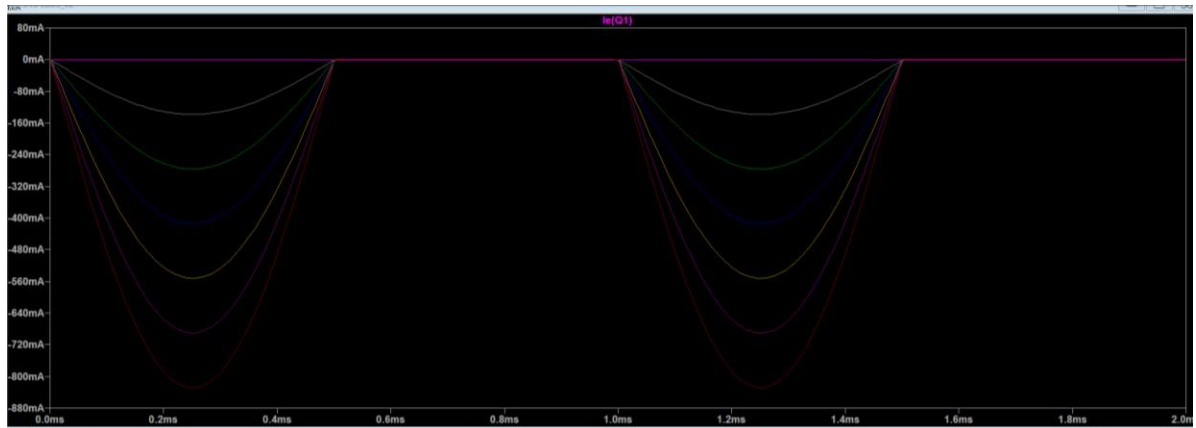


Figure 3: Emitter current of Q1

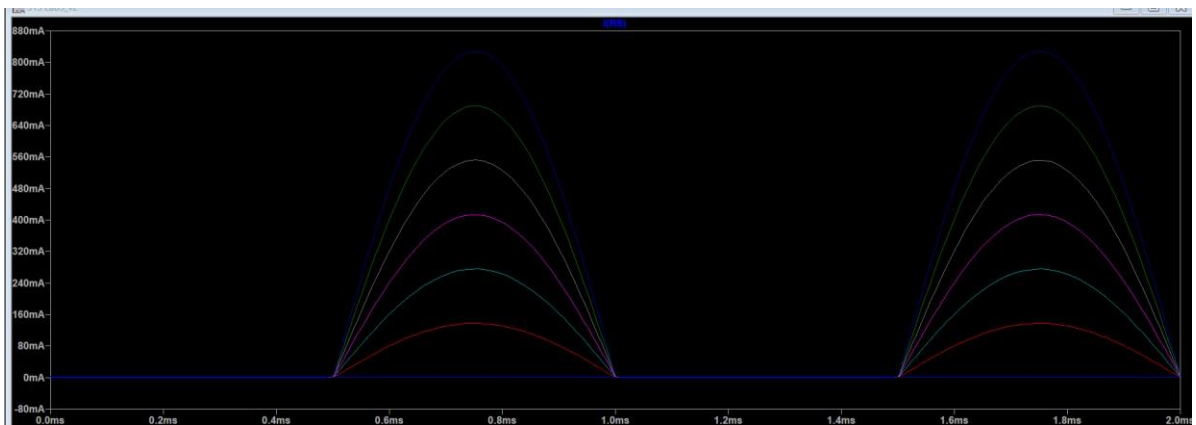


Figure 4: Emitter current of Q3

The current is zero for half the period as expected.

After distortion is solved, I started to give some arbitrary values for the resistors R2, R3, R4 and R5, which I observe they are affecting the efficiency of the circuit,  $P_{out}$  (power dissipation),  $P_s$  (input power) and the regions bjt's are working so that the shape of the sine wave we are given as input. I arranged the supply voltage to be at most  $\pm 9V$ . I expected the sinusoidal voltages operate between 10Hz and 20KHz with a gain between 15 dB and 25 dB. With some trail and error I concluded with the below circuit:

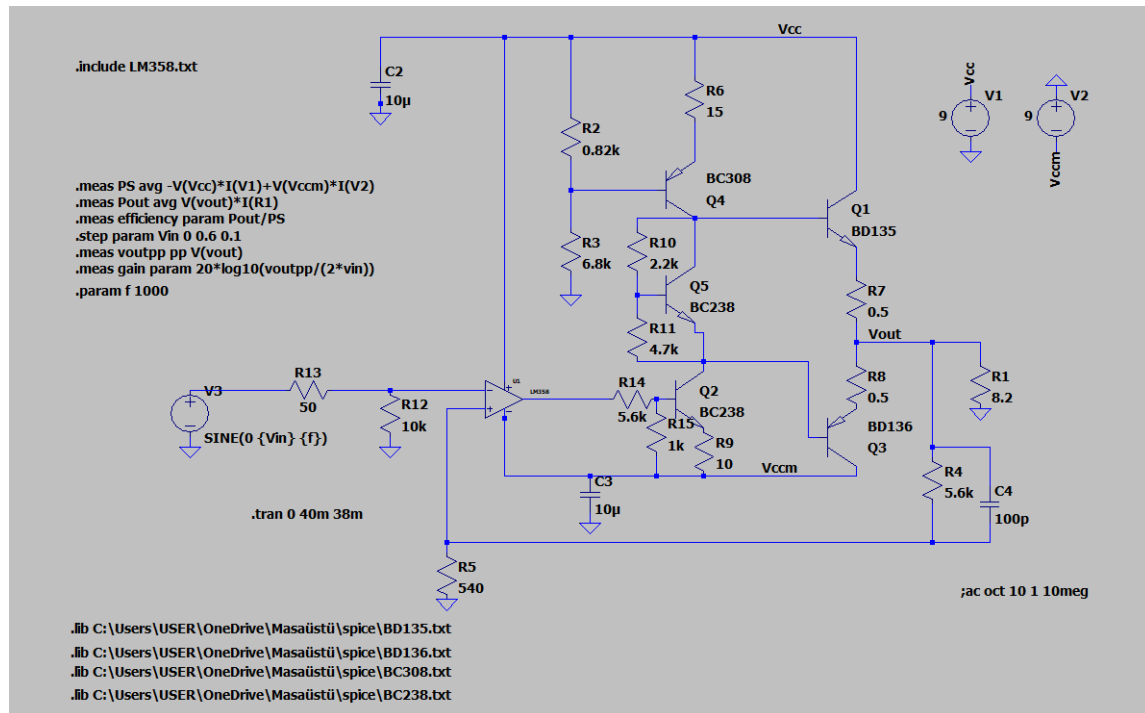


Figure 5: Overall Circuit Design

Now, Let's check whether our circuits obeys the specifications we are given.

## Specification 1

The amplifier should deliver at least a 2.19W power to an 8.2Ω resistance (12Vpp to an 8.2Ω power resistor) starting from 10Hz to 40KHz at the chosen gain value.

We take Vin starting from 0 to 0.6 with the steps of 0.1 with the command **.step param Vin 0 0.6 0.1**. But we are checking the 0.6V input, so we will check the last term of the table. As seen below table, we first made sure that our circuit delivers approximately 2.25W at 1kHz frequency (because initially we are starting from this frequency) then we continue checking specific frequency values whether our power is lower than 2.19W or not.

step	AVG(v(vout)*i(r1))
1	1.29946e-006
2	0.0779027
3	0.311304
4	0.700383
5	1.24523
6	1.94586
7	2.80325

**.param f 1000**

<b>.param f 10</b>	Measurement: pout	
	step	AVG(v(vout)*i(r1))
	1	1.29946e-006
	2	0.0640243
	3	0.25457
	4	0.571441
	5	1.01513
	6	1.58581
	7	2.28235
<b>.param f 2000</b>	Measurement: pout	
	step	AVG(v(vout)*i(r1))
	1	1.29946e-006
	2	0.0775223
	3	0.310075
	4	0.697673
	5	1.24041
	6	1.93791
	7	2.79051
<b>.param f 5000</b>	Measurement: pout	
	step	AVG(v(vout)*i(r1))
	1	1.29946e-006
	2	0.0759973
	3	0.303457
	4	0.682658
	5	1.21377
	6	1.90114
	7	2.75035
<b>.param f 10000</b>	Measurement: pout	
	step	AVG(v(vout)*i(r1))
	1	1.29946e-006
	2	0.0750492
	3	0.300337
	4	0.677499
	5	1.21147
	6	1.9022
	7	2.74978
<b>.param f 20000</b>	Measurement: pout	
	step	AVG(v(vout)*i(r1))
	1	1.29946e-006
	2	0.0747432
	3	0.298748
	4	0.672155
	5	1.20526
	6	1.89028
	7	2.73313
<b>.param f 40000</b>	Measurement: pout	
	step	AVG(v(vout)*i(r1))
	1	1.29946e-006
	2	0.0734149
	3	0.291117
	4	0.6578
	5	1.17406
	6	1.83678
	7	2.65532

So, specification 1 satisfied.

## Specification 2

The harmonics (the highest is possibly the third harmonic) at the 2.25W output power level should be at least 40 dB lower than the fundamental signal at 1 KHz.

To check this we need to simulate with 20 cycles visible on the plot window. Then, right-click on the plot window, View → FFT, to see the amplitude of different harmonics. We can find the dB difference between the fundamental (at 1 KHz) and the third harmonic (at 3 kHz).

Here is my plot look like:

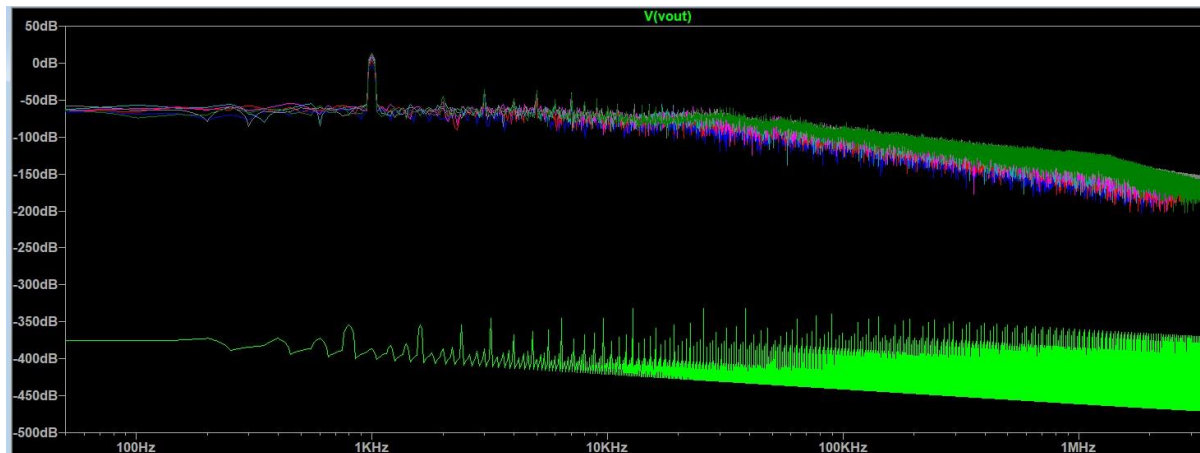


Figure 6: dB Difference

### Specification 3

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

In an amplifier circuit, the quiescent condition is the state when there is no input signal applied, and the amplifier is simply maintaining its operating point or biasing conditions. During quiescence, the amplifier consumes power, but it does not produce any significant output signal. The input power that we needed to check with zero input with the command `.meas PSavg -V(Vcc)*I(V1)+V(Vccm)*I(V2)`. (At 1kHz)

Measurement: ps		
step	AVG (-v(vcc)*i(v1)+v(vccm)*i(v2))	
1	0.326134	0
2	1.09904	0
3	1.8815	0
4	2.66337	0
5	3.44445	0
6	4.22479	0
7	5.00449	0

Figure 7:  $P_s = 326mW$  when  $V_{in}=0V$

### Specification 4

The amplifier's overall efficiency (output power/total supply power) should be at least 45% at max power output at 1kHz.

Efficiency is calculated with the ratio of output power and total supply power which is:

$$\eta = \frac{P_{out}}{P_s} \quad (\text{eqn. 2})$$

Measurement: efficiency	
step	pout/ps
1	3.98444e-006
2	0.0708822
3	0.165455
4	0.262969
5	0.361517
6	0.460582
7	0.560146

Figure 8: Efficiency is calculated about 56%

Efficiency is calculated about 56% which is higher than 45% and meeting the expectations.

Lastly, here is my Vout plot and Vout values with respect to given Vin:

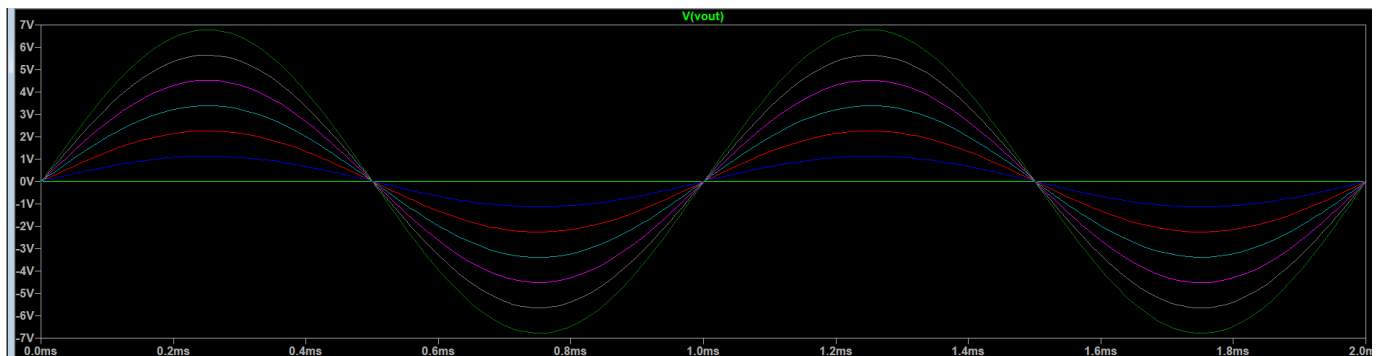


Figure 9: Vout Plot

Measurement: voutpp	
step	PP (v (vout) )
1	0
2	2.26105
3	4.51995
4	6.78057
5	9.04478
6	11.3059
7	13.5663

Figure 10: Vout peak to peak values, Vout= 13.566V



At the max level of  $V_{out}$  has be around 12Vpp as we are expected. In my observations I see a little higher than that will higher the efficiency and  $P_{out}$  so that they satisfy the expectations.

My gain was always between 15 and 25dB as required and never changed that much while I am doing trial and error.

```
Measurement: gain
step      20*log10(voutpp/(2*vin))
1         -1.#IND
2         21.0656
3         21.0615
4         21.0623
5         21.0662
6         21.0661
7         21.0656
```

*Figure 11: Gain values, 21dB*

## Conclusion

The design and testing process of a complementary push-pull Class-B power amplifier was required to deliver a minimum of 2.25W to an 8.2Ω resistive load over a frequency range of 10Hz to 40KHz, with specific criteria for harmonic distortion, quiescent power consumption, and overall efficiency. Through careful component selection and circuit configuration, the amplifier successfully met all specified requirements. The report discusses the iterative process of circuit design, including stability checks and adjustments to component values to optimize performance. Simulation results and measurements were used to verify the amplifier's compliance with specifications, including power output, harmonic distortion levels, quiescent power consumption, and efficiency. By engaging in this lab, I not only deepen their understanding of amplifier design principles but also develop the practical skills and problem-solving abilities necessary.

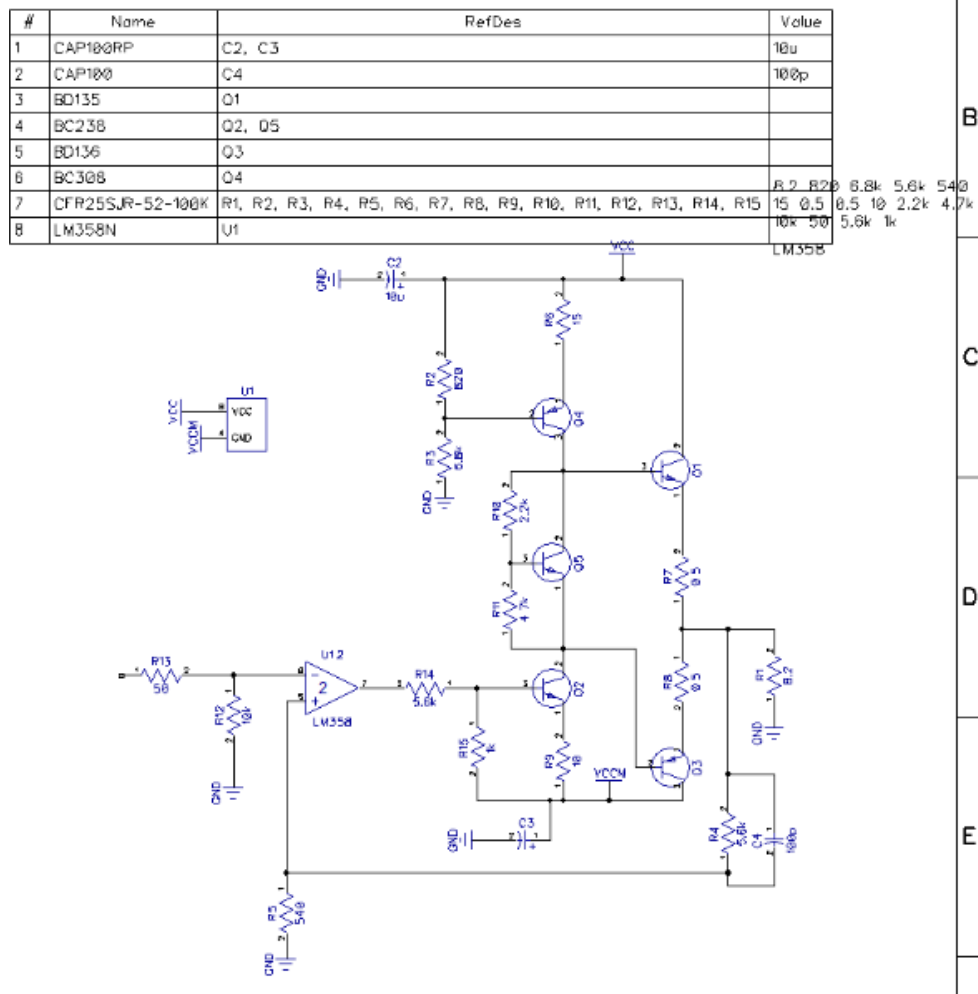
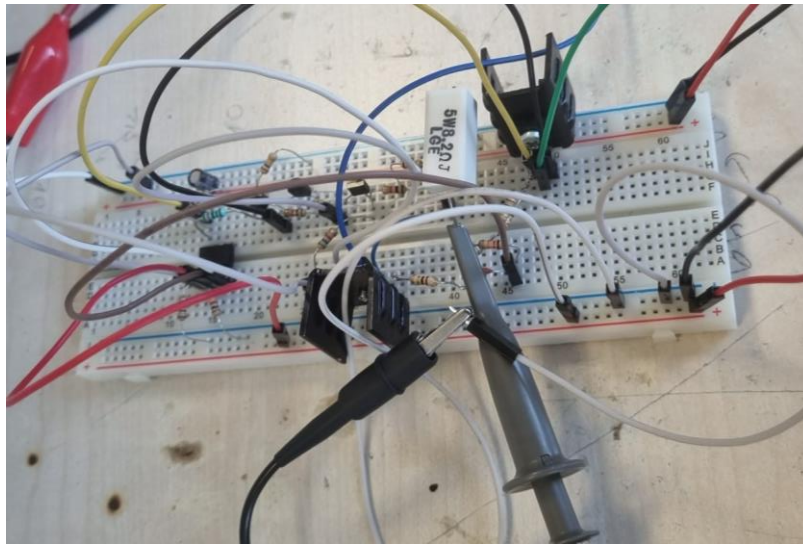


Figure 12: DipTrace Schematic of my Circuit

## Experimental Work

In this part due to some errors and I got lower Output voltage and also, my current source BJT Q4(BC308) was not working properly and supplying a very low current I needed to change some of my resistance values for example R2 and R3. I also observed a saturation in my sine wave on the oscilloscope screen so that, I lower my input voltage to 0.45 to 0.5 from 0.6. By doing this my output voltage stayed in the range between 10V and 11V so it satisfies the specifications given us.



*Figure 13: My overall, working circuit*

I got some issues with working 5bjt's, at the very beginning of the lab, I burnt one of my bjt's and tried to find the error which took my time. After that, I started to use heat sink which then inhibits my transistors to burn. Also, there were lots of jumpers and connections at the very beginning. Then, I used shorter and neat connections because controlling the connections was hard and I realized I missed some of my wire connections after double checking.

As recommended us before, I connected 100Ω resistors in series with each supply line while debugging my circuit. I applied the supply voltages while gradually increasing. The supply currents were about 20 to 30mA each after I corrected my circuit I measured my transistor's leg voltages with the multimeter making sure that they all work in the ACT region.

### Specification 1

As I observed the output current (through R1) didn't change much from 0.2mA (always higher than that), so by calculating the power delivered to 8.2Ω resistance, the output power  $P_{out}$  stays the desired range around 2 to 2.7 mW. ( $0.2\text{mA} \times 11\text{V} = 2.2\text{mW}$ ). I didn't put the output current in here, because it didn't change much when I played with the frequency as seen in the Figures below (Figures 14 to 20). Also from the below Figures we can see  $V_{cc}$  and  $V_{cm}$  values, the input currents,  $V_{in}$  value and from the oscilloscope screen we can observe  $V_{out}$  value and the frequency we apply.

At 40kHz



Figure 14:  $V_{out} = 11.2V$ ,  $f = 40kHz$ ,  $P_{out} \approx 2.46W$  ( $11.2V \times 22mA$ )

At 10kHz



Figure 15:  $V_{out} = 10.9V$ ,  $f = 10kHz$ ,  $P_{out} \approx 2.18W$  ( $11.2V \times 2mA$ )

At 5kHz

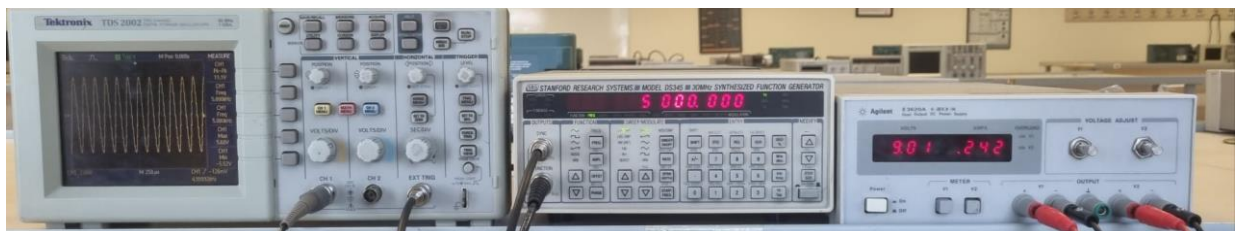


Figure 16:  $V_{out} = 11.1V$ ,  $f = 5kHz$ ,  $P_{out} \approx 2.33W$  ( $11.1V \times 21mA$ )

At 2kHz



Figure 17:  $V_{out} = 11.3V$ ,  $f = 2kHz$ ,  $P_{out} \approx 2.73W$  ( $11.3V \times 21mA$ )

At 1kHz

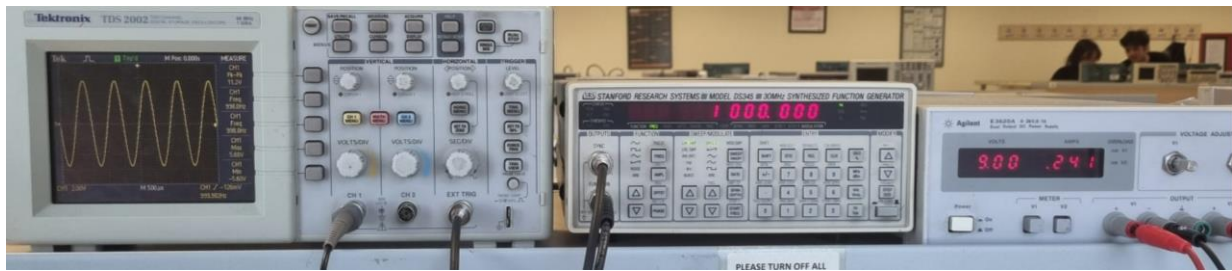


Figure 18:  $V_{out} = 11.2V$ ,  $f = 1kHz$ ,  $P_{out} \approx 2.58W$  ( $11.2V \times 23mA$ )

At 100Hz



Figure 19:  $V_{out} = 11.0V$ ,  $f = 100Hz$ ,  $P_{out} \approx 2.42W$  ( $11.0V \times 22mA$ )

At 10Hz



Figure 20:  $V_{out} = 11.0V$ ,  $f = 10Hz$ ,  $P_{out} \approx 2.20W$  ( $11.0V \times 2mA$ )

As seen in the figure my output voltage didn't change much so does my output current through RLoad and I got at least 2.19W power from the output as expected so specification 1 satisfied.

## Specification 2

The harmonics at the 2.25W output power level should be at least 40 dB lower than the fundamental signal at 1 KHz and this specification is checked with the FFT property of the oscilloscope.



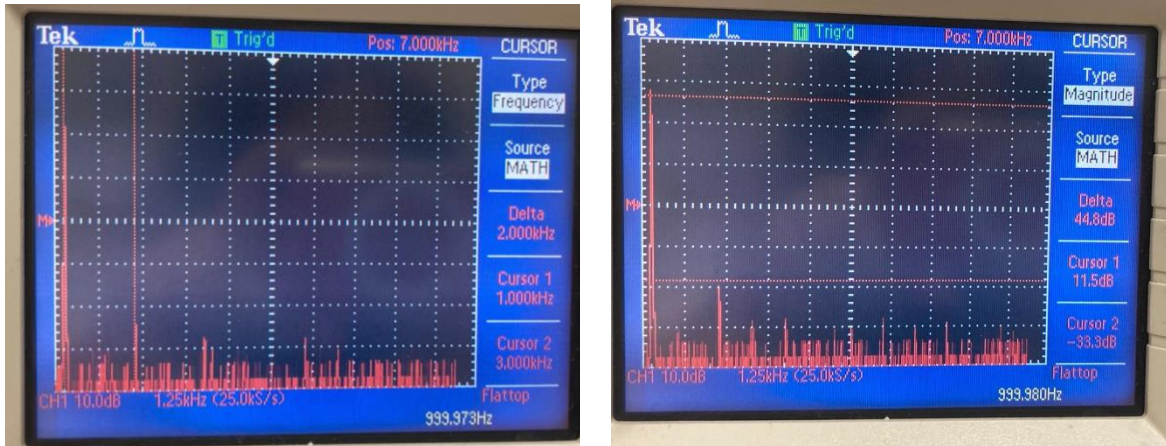


Figure 21: The gain difference between the fundamental and third harmonic = 44.8dB

### Specification 3

The power consumption at quiescent conditions should be less than 500mW and at that condition we need to get about 15mA and 25mA. When we give 0 V as an input we're in the quiescent condition. Here is my observations and results:

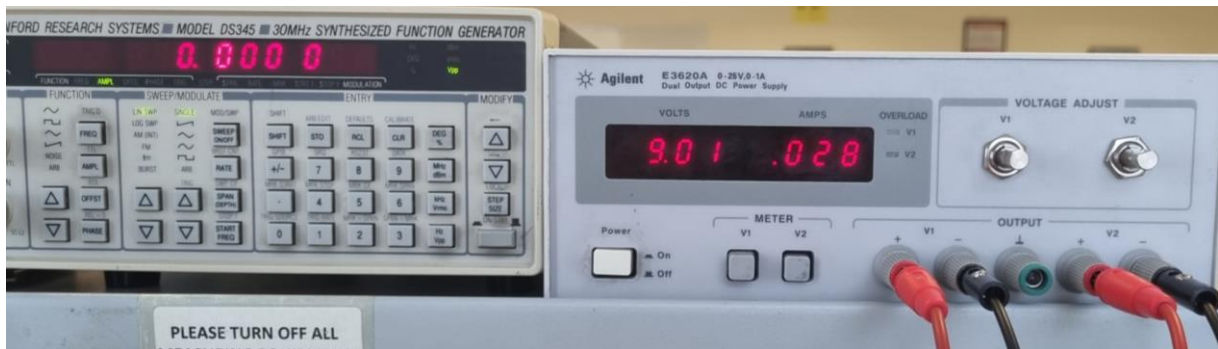


Figure 22:  $9.01V \times 0.028mA = 252.3W$  at the quiescent condition

252.3W at the quiescent condition which less than 500mW and satisfies the condition.

### Specification 4

The amplifier's overall efficiency should be at least 45% at 1KHz.

At the Figure 18  $V_{out}$  is found about 2.58W. Since efficiency found from eq. 2 and PS found from  $.meas PS_{avg} - V(V_{cc}) * I(V1) + V(V_{ccm}) * I(V2)$ , from the Figure 18  $V_{cc} \times I_{in}$ , and  $V_{cc}$  and  $V_{ccm}$  are equal in magnitude and  $I_{in}$  won't change much from  $V1$  to  $V2$  we can derive it by multiplying  $V_{cc} \times I_{in}$  with 2.

$$\eta = \frac{2.58}{2(9 \times 0.242)} = 0.592 = 59.22\%$$

As seen from the above equation the efficiency is found about 59.22% which satisfies the specification 4.

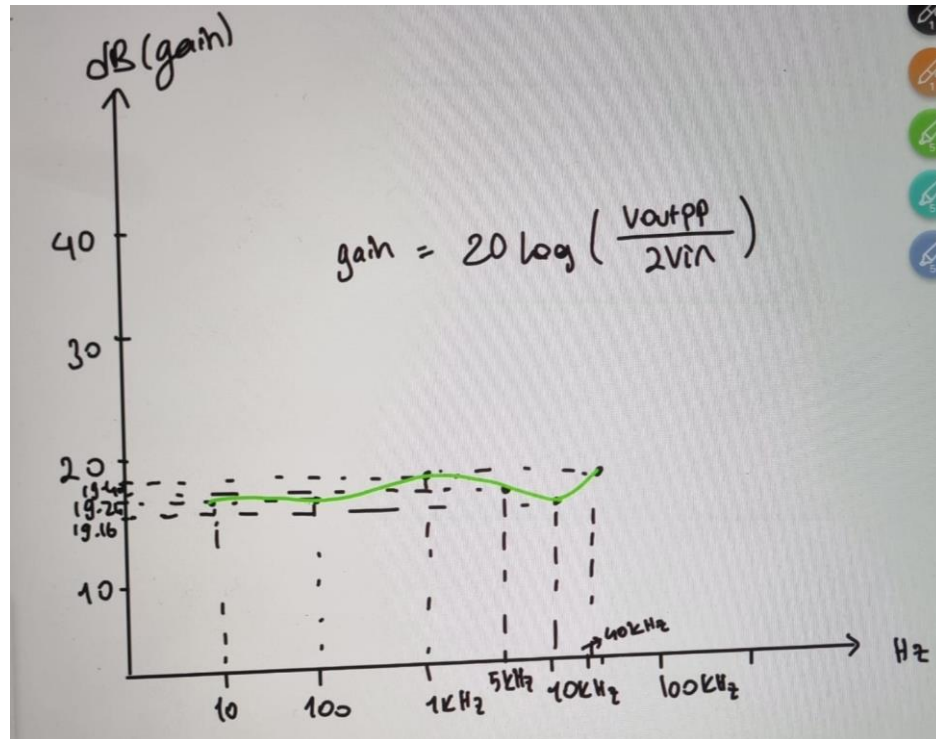


Figure 23: Gain plot as a function of frequency at max input level

## References

[https://moodle.bilkent.edu.tr/2023-2024-spring/pluginfile.php/78197/mod\\_resource/content/1/BD136.txt](https://moodle.bilkent.edu.tr/2023-2024-spring/pluginfile.php/78197/mod_resource/content/1/BD136.txt)

[https://moodle.bilkent.edu.tr/2023-2024-spring/pluginfile.php/97549/mod\\_resource/content/1/Lab3Hints.pdf](https://moodle.bilkent.edu.tr/2023-2024-spring/pluginfile.php/97549/mod_resource/content/1/Lab3Hints.pdf)

[https://moodle.bilkent.edu.tr/2023-2024-spring/pluginfile.php/93138/mod\\_resource/content/3/Lab3.pdf](https://moodle.bilkent.edu.tr/2023-2024-spring/pluginfile.php/93138/mod_resource/content/3/Lab3.pdf)

<https://www.electronicdesign.com/technologies/power/whitepaper/21215797/electronic-design-what-is-the-essence-of-quiescent-current>

Lecture notes from Instructor Abdullah Atalar, Spring 2024