Complex Engineering Problem

Design, Simulation and Hardware Implementation of a Class AB Output Stage Amplifier

CEP Report

Group # 4

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Abstract

This engineering report details the design and implementation of a Class AB audio amplifier, combining the VBE multiplier biasing with a Darlington Pair using TIP 31/32 transistors for enhanced performance. The project involved careful component selection, theoretical calculations, and simulations in NI Multisim 14.3, followed by practical implementation and testing. The designed amplifier successfully maintained consistent quiescent current, minimized total harmonic distortion (THD), and provided satisfactory gain and power output. The report encapsulates the challenges and adjustments encountered during the hardware implementation, resulting in a high-fidelity audio output with a 4 Ω, 10 W speaker, demonstrating the effective integration of theoretical principles with practical application in audio amplification.

1. Introduction

This report delves into our team's collective effort in designing a class AB audio amplifier, a complex task having contradicting requirements. It required a delicate balance between precision and efficiency.

1.1. Class AB Amplifier

In the realm of audio amplification, where the pursuit of efficiency meets the demand for high-fidelity sound reproduction, Class AB amplifiers emerge as a sophisticated and widely employed solution. These amplifiers represent a harmonious compromise between the distinct characteristics of Class A and Class B amplification, offering an optimal blend of efficiency and low distortion. As a cornerstone in the design of audio systems, Class AB amplifiers play a pivotal role in delivering nuanced, powerful, and faithful reproduction of audio signals across a diverse array of applications.

Class AB amplifiers owe their nomenclature to the operating class they belong to within the broader spectrum of amplifier classifications. Bridging the gap between the continuous operation of Class A amplifiers and the efficiency-driven operation of Class B amplifiers, Class AB designs aim to mitigate the shortcomings inherent in each, resulting in an amplifier architecture that excels in balancing performance metrics. Furthermore, class AB amplifiers are classified by the biasing configuration used. The different types of biasing are resistive biasing, diode biasing, V_{BE} multiplier biasing and emitter follower biasing. We have used the V_{BE} multiplier biasing coupled with the Darlington pair for the design of this audio amplifier.

1.2. V_{BE} Multiplier Biasing

At its core, V_{BE} Multiplier configuration provides a dynamic voltage drop across the two power transistors of the Class AB amplifier. This unassuming yet effective mechanism proves quite handy in maintaining a consistent, small quiescent current through the output transistors.

During the transitions between positive and negative signal halves, which can be prone to distortion in Class AB amplifiers, the V_{BE} multiplier steps in with a subtle finesse. By keeping the biasing conditions under check, it ensures that the output transistors smoothly navigate through these transitions, preventing any unwanted distortion from appearing in the output.

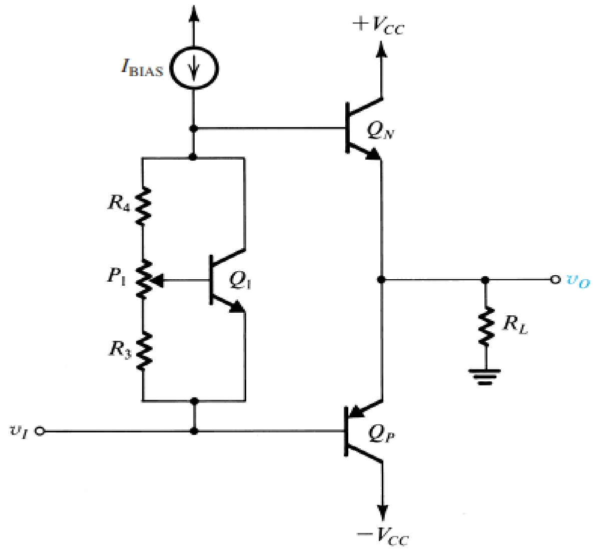

Figure 1: V_{BE} Multiplier Class AB Amplifier

In essence, the multifaceted role of the V_{BE} multiplier, extending beyond a mere voltage drop mechanism, and the preservation of audio signal integrity. This nuanced intervention makes the V_{BE} multiplier an indispensable element, elevating the performance of Class AB amplifiers.

1.3. Darlington Pair

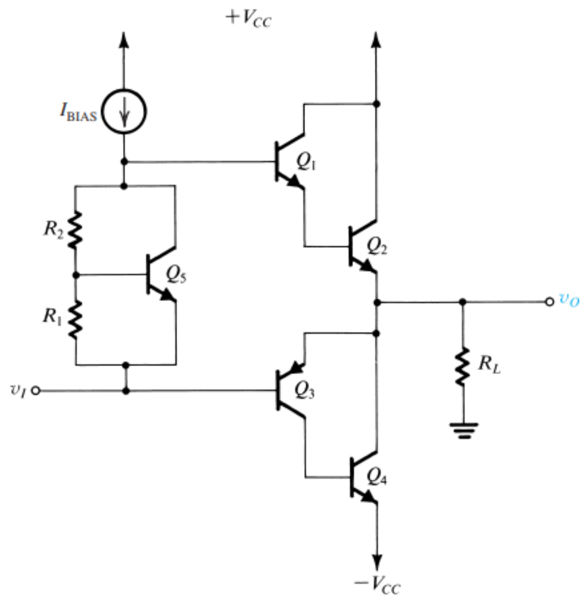

Figure 2: Class AB Amplifier Utilizing Darlington Pair Biased by V_{BE} Multiplier.

The Darlington Pair, a configuration comprising two bipolar junction transistors (BJTs) cascaded together, offers distinct advantages that align seamlessly with the goals of Class AB amplification. As this tandem arrangement amplifies the incoming signal, it enhances the overall gain of the amplifier, facilitating the attainment of higher levels of power efficiency. The inherent nature of the Darlington Pair allows for a significant reduction in the input current required to drive the transistors, making it an efficient choice for amplifiers where energy conservation is a paramount concern.

Moreover, it is quite effective in increasing the input resistance of the amplifier and decreasing the output resistance as the gain of the small signal transistor used for the purpose of making a Darlington Pair is significantly higher than the power amplifiers.

The overall advantages of using a Darlington Pair can be summarized in the following points:

- It offers very high current gain in comparison to single transistor;
- It offers very high input resistance;
- It can amplify signals to a larger extent;
- It allows designers to drive more power applications by a few mA of current source;

1.4. Component Selection and Configuration

In this CEP, we used some specific components to make our circuit and implement it. Every component was selected precisely to provide the best possible outcome. The only component we were bound to use was TIP 31/32 for the Darlington Pair as it was specified in the CEP statement. In this section we will provide a list of the components we used.

Table 1: List of Components

Component	Usage
2N2222	V_{BE} Multiplier
2N3904	Darlington Pair (+ ve)
2N3906	Darlington Pair (- ve)
TIP 31C	Darlington Pair (+ ve)
TIP 32C	Darlington Pair (- ve)
LM741	Input Stage OP-Amp

2. Design Calculation

The power and resistance of the output load is given,

$$P_L = 10\ W$$

$$R_L = 4\ \Omega$$

Since, we are aware of the formula for P_L, we can modify it for ${v_o}^2$

$$P_L = \frac{{v_o}^2}{2R_L}$$

$${v_o}^2 = 2R_L P_L$$

$$\boldsymbol{v_o} = \mathbf{8.94\ V \cong 9\ V}$$

Now, the formula for efficiency is known to us,

$$\eta = \frac{\pi v_o}{4V_{cc}}$$

$$\boldsymbol{\eta} = \mathbf{64.2}\ \%$$

Let us assume that $I_Q = 300\ mA$, we can use it to calculate further,

$$\boldsymbol{I_Q = 300\ mA}$$

$$I_B = \frac{I_Q}{\beta_1 \beta_N}$$

$$I_B = \frac{300}{100\ \times\ 25} = 0.12\ mA$$

$$R = \frac{V_{CC}\ -\ (0.7\ +\ 1.8)}{2}$$

We take $V_{CC}\ =\ 11$ V and use it to calculate the required resistances of the circuit,

$$\boldsymbol{R = 4.25\ \Omega}$$

$$V_{BB} = 2.64\text{ V}$$

$$V_{BE3} = V_T \ln \frac{I_C}{I_S}$$

$$V_{BE3} = 0.025 \ln \frac{10^{-3}}{10^{-15}} = 0.7\ V$$

$$\boldsymbol{R_{b1}} = \frac{2.64 - 0.8}{0.88} = \boldsymbol{1.9\ k}\Omega$$

$$\boldsymbol{R_{b2}} = \frac{V_{BE3}}{0.88} = \boldsymbol{800}\ \Omega$$

$$R_{in} \gg \frac{1}{2\pi f C}$$

$$C \gg \frac{1}{1000} \times 2\pi \times 5000$$

$$C \gg 3.18 \times 10^{-8}\ F$$

We take $C = 100\ \mu F$ so that we could adjust for the required frequency, and input resistance,

$$R_{in} = \frac{(R\,||\,R \times \beta_1 \beta_N R_L)}{(R\,||\,R + \beta_1 \beta_N R_L)}$$

$$\boldsymbol{R_{in} = 1.7\ k}\Omega$$

$$R_{out} = \frac{r_{en} + (R\,||\,R)}{\beta_1 \beta_N}$$

$$R_{out} = \frac{0.08 + (4125\,||\,4125)}{25 \times 100}$$

$$\boldsymbol{R_{out} = 0.083}\ \Omega$$

3. Simulations and Results

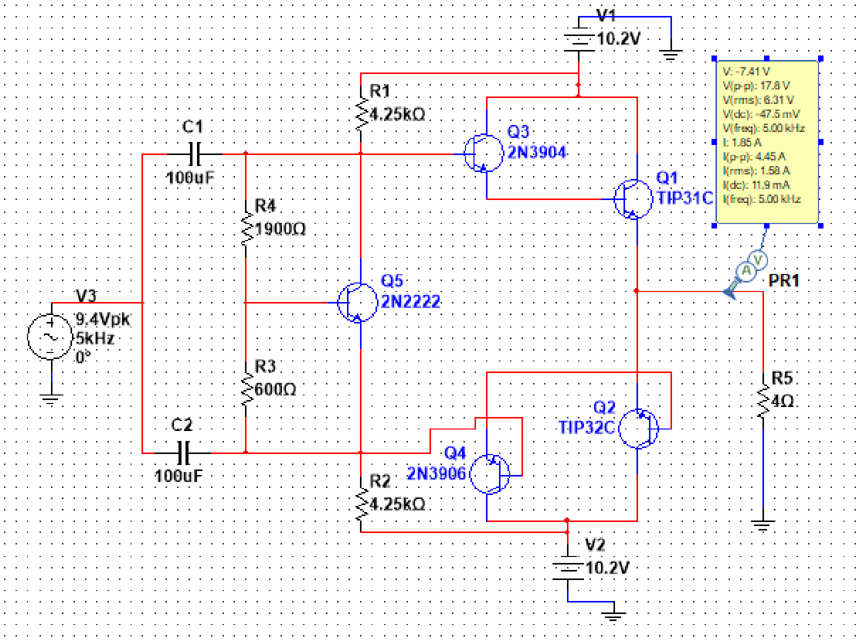

Figure 3: Simulated Circuit

The design calculations were employed to simulate the Class AB audio amplifier. The software we used to simulate the circuit is NI Multisim 14.3. The simulated circuit was working as intended and filled the required parameters as well as shown in Figure 3. We were able to get an output wave with 8.4 V amplitude.

The output waveform is shown below:

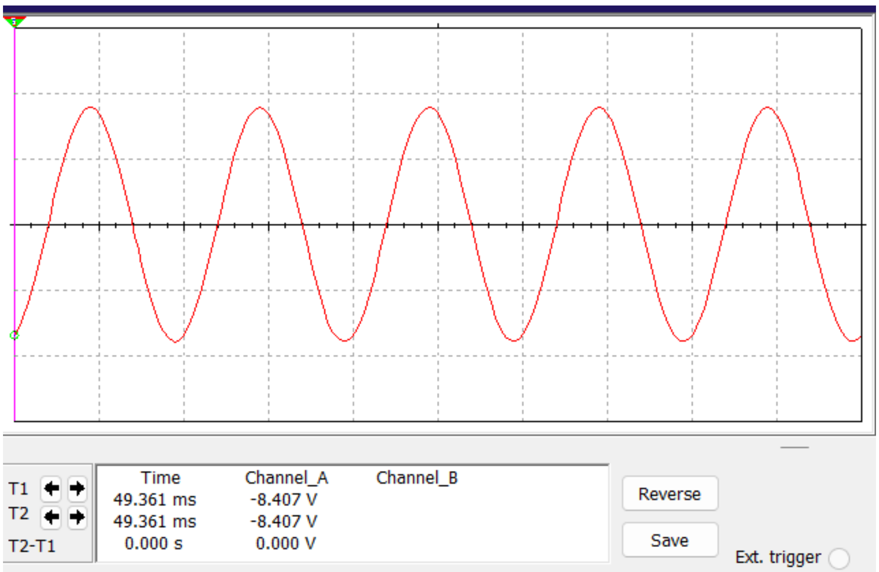

Figure 4: Output Waveform

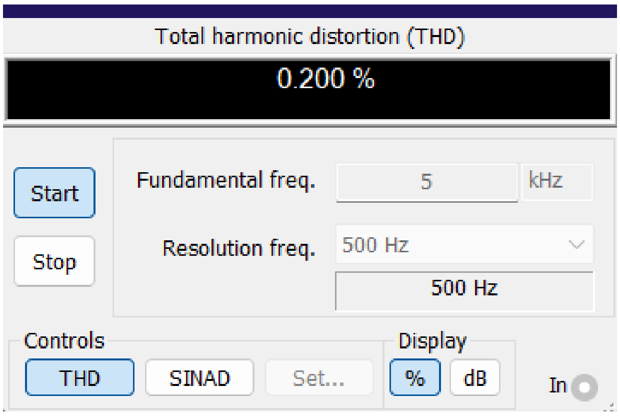

Figure 5: THD Analyzer

Total Harmonic Distortion (THD) is a measure of the extent to which the harmonic frequencies of a signal deviate from the desired pure sinusoidal waveform. It can be seen in the output waveform that there is almost no zero-crossover or saturation distortion in the output, resulting in minimum distortion. The total harmonic distortion (THD) was also measured for the simulated circuit as shown in Figure 5 which came out to be 0.2%. It was well within the given criteria.

The current flowing through the 4 Ω load is 1.58 A (refer Figure 4). Considering the voltage across the load along with the current flowing through it we calculate the power to be around 10 W which is completely in accordance with the requirements of the CEP.

Here is a table which provides the minor changes we had to do to the calculations during simulations,

Table 2: Comparison of Specifications

Component	**Theoretical Specifications**	**Simulated Specifications**
R	4.25k Ω	4.25k Ω
R_{b1}	1.9k Ω	1.9k Ω
R_{b2}	0.8k Ω	0.6k Ω
V_{CC}	11 V	10.2 V
R_{in}	1.7k Ω	1.5k Ω
R_{out}	0.083 Ω	0.043 Ω

As shown in Table 2 some changes are made to the initial calculations. We changed the V_{CC} from 11 V to 10.2 V this in turn improved our overall efficiency. We decreased R_{b2} from 0.8k Ω to 0.6k Ω allowing us to increase the I_Q which effects our THD directly, decreasing it immensely and essentially making our signal clearer and increasing the overall efficiency as well.

The results of the simulation show that the design calculations are indeed correct, and we can move on to the next stage of this CEP which is the implementation of the amplifier design on hardware.

4. Hardware Implementation and Results

The practical implementation of the circuit was done on a breadboard. The implemented circuit is shown in Figure 6. Some more changes were done to the practically implemented circuit to tackle the observed issues and improve the overall working of the circuit.

It can be seen in the circuit that other than the two coupling capacitors various more capacitors are also added. As shown in the bottom of the figure two small capacitors of 10 µF are added at the V_{CC}, these capacitors act as a low pass filter removing any noise, that may come from the input voltage we provide from the power supply further improving our signal.

We also added two small capacitances of 0.1 µF in parallel to load which also act to remove any noise from the signal that is going across the load providing a smooth output signal.

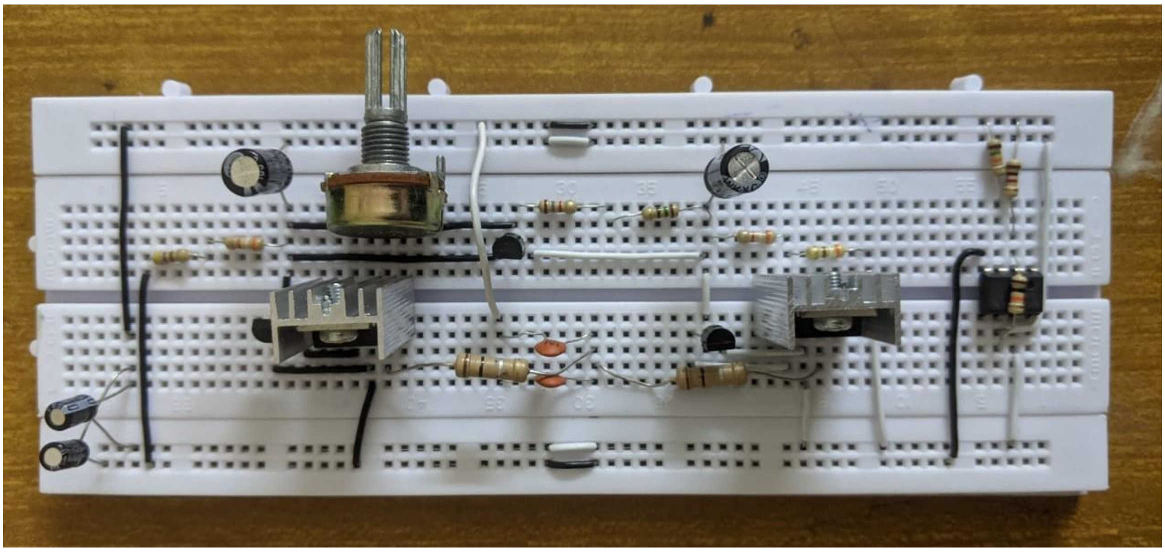

Figure 6: Practically Implemented Circuit

Table 3: Practical Component Parameters

Component	**Practical Specifications**
R	4.24k Ω
R_{b1}	1.89k Ω
R_{b2}	0.62k Ω
V_{CC}	10.2 V
R_e	0.3 Ω

Thermal resistances in a circuit quantify the ability of components to impede heat flow, aiding in the analysis and design of temperature management systems. We added two thermal resistors of 0.3 Ω each of 1 W to compensate the heat and power dissipation. These were selected based on proper calculations.

$$I_{pk} = 2.25 \text{ A}$$

$$I_{thermal\ resistor} = \frac{2.25}{2} = 1.12\ A$$

$$P_{thermal\ resistor} = I^2\text{R} = 0.37 \text{ W}$$

From these calculations we can confirm that the resistor we need must have a power rating greater than 0.37 W so because of easier availability we chose the resistor with 1 W power rating.

We can also check the power rating across each transistor using a similar calculation,

$$P_{transistor} = V_{cc}I_{bias} = 3.3 \text{ W}$$

In the practical implementation we also implemented the input stage. For that we use an OP-AMP IC which was LM741, we set a fixed gain of 10 for the OP-Amp. The gain the OP-Amp can also be used as volume control, the higher it is the more the sound and vice versa.

As shown in Table 3 some minor changes in the value of resistances are also noticed, these are due to the practical limitation of the resistances we used. Due to tolerance and other factors, they are usually not equal to the required resistance.

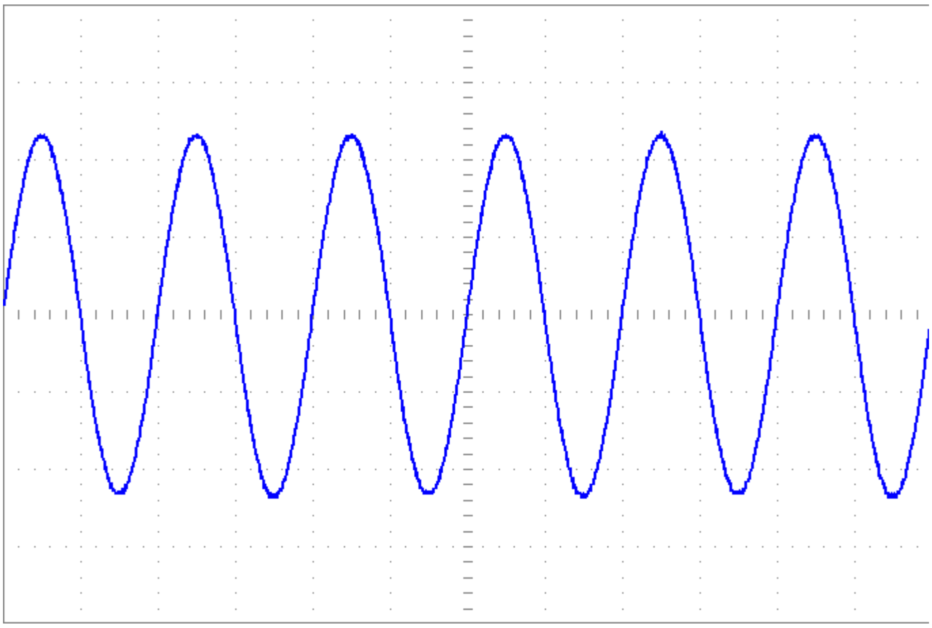

Figure 7: Output Waveform of the Practical Circuit

The output wave across the load of 4 Ω and 10 W is shown in Figure 7. With an input sine signal of 9.4 V_{PK} and 10.2 V_{CC}, we got an output wave of 7.6 V_{PK} giving us an efficiency of 60.69 % which is according to the requirements of the CEP statement.

Calculation of some important parameters are done below:

Using the Digital Multimeter (DMM) we can get the voltage at the output and V_{CC} and I_{bias} is shown on the power supply,

$$v_o = 7.60 \text{ V}$$

$$I_{bias} = 0.6\ A$$

$$V_{cc} = 10.2 \text{ V}$$

Using the above parameters, we can the power supplied,

$$P_S = 2V_{cc}I_{bias} = 12.2\ W$$

$$P_L = \frac{{v_o}^2}{2R_L} = 7.4\ W$$

$$\eta = \frac{P_L}{P_S} = 60.69\ \%$$

Table 4: Observed dB from FFT at Different Frequencies

Frequency	**dB**	**V_{RMS}**
1 kHz	11.6	3.80
3 kHz	-33.2	0.021
5 kHz	-38	0.0125
7 kHz	-43.6	0.0066

Now to calculate the THD, we must observe the FFT and get the dB values at different frequencies. The Table 4 gives the dB values at different frequencies. Using these we can find the THD of the circuit.

$$THD = \frac{\sqrt{\sum {V_{rms}}^2}}{V_i} \times 100$$

Here we sum all the voltages we get for different frequencies and divide them by the first one,

$$THD = 0.66\ \%$$

The gain of the circuit is another important parameter that can help us as well,

$$Gain = \frac{V_o}{V_{in}} \times 100 = 80.85\ \%$$

$$\frac{Output\ Swing}{V_{cc}} = \frac{7.60}{10.2} \times 100 = 74.5\ \%$$

The parameters found above are very important for our circuit and confirming that it was implemented properly and will work as intended. With a decent gain and THD we can confirm that we will be able to get comprehendible audio signal on the output.

We applied an audio signal to the OP-Amp after confirming all the parameters and their correctness. In the place on the load, we used a 4 Ω and 10 W speaker. After confirming the condition of the circuit in DC conditions, we apply the audio signal, and the audio is heard on the output from the speaker indicating our circuit was working as intended.

5. Discussion

Some important observations we noted during the implementation of the CEP must be discussed before concluding the report. These observations not only make up our understanding of the whole CEP but also answers many of the changes we had to make in the practical implementation. This section serves to answer all such things.

5.1. Why do we observe lower current gain when applying audio signal as compared to sine signal?

The audio signal is a dynamic signal and has varying amplitude. The amplifier's behavior changes to accommodate this dynamic signal characteristic. Another point to note is in a Class AB amplifier, biasing is set to ensure that both the NPN and PNP transistors conduct slightly even in the absence of a signal, reducing crossover distortion. When an audio signal is applied, the biasing requirements may change, affecting the operating point of the transistors and, consequently, the current flow. Amplifiers, especially in the presence of large signals, may exhibit compression effects as well. As the audio signal amplitude increases, the amplifier may enter a region where it approaches saturation or its maximum output capability. This can result in the reduction of effective gain and, consequently, a decrease in current or the audio signal may cause variations in the load impedance seen by the amplifier, impacting the overall current drawn from the power supply. All the above noted points may be the reason behind our decrease in current when we apply an audio signal.

5.2. How do we choose the polarity of the input capacitor?

The choice of the polarity of the capacitor depends on the DC biasing we do. When we add a capacitor to the input after the sine signal it must act as a blockade, blocking all the DC signal from passing through or coming back and only allowing AC signal to pass through. This helps us in setting the orientation of the capacitor. For example, on the positive DC biased side we must make sure that it doesn't travel towards the input signal, so we select the positive side of the capacitor to face the rest of the circuit and negative side to face the input signal and vice versa in the other case.

5.3. When is max power dissipated across transistors?

When peak output signals are applied on the circuit, both NPN and PNP transistors are active and there is an overlap region where both transistors conduct simultaneously. This overlap results in higher current flowing through both transistors, leading to an increased power dissipation. The power dissipation is at its maximum during these periods of overlap when both transistors are conducting, and the amplifier is handling high-output signals.

6. Conclusion

In conclusion, our engineering report encapsulates the meticulous efforts invested in conceiving and implementing a Class AB audio amplifier, striking a delicate balance between precision and efficiency. The integration of VBE multiplier biasing with the Darlington pair enhanced performance and embodied the synergy between theoretical principles and practical application. Rigorous component selection, driven by project requirements, played a pivotal role, while theoretical insights and practical considerations, including simulations using NI Multisim 14.3, validated the design's effectiveness. The hardware implementation, marked by adjustments to address practical challenges, affirmed the success of our approach, with critical parameters such as total harmonic distortion (THD), gain and efficiency falling within acceptable limits. Testing with a 4 Ω, 10 W speaker provided a conclusive demonstration of a clear and comprehensible audio output. This project not only attests to the successful design and implementation of a Class AB audio amplifier but also deepens our understanding of the intricate interplay between theoretical design and practical application in audio amplification technology.