Experiment 4: Push-Pull Amplifier

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Experiment 4, Push-Pull Amplifier

I. Purpose

The main objective of this experiment is to understand the operation and applications of a push-pull amplifier by physically building the circuit. A push-pull amplifier utilizes two complementary transistors (typically NPN and PNP), where each transistor conducts during opposite halves of the input signal cycle—positive and negative, respectively. This alternating operation allows for efficient signal amplification while reducing power consumption.

We can observe the output waveform through practical implementation and measurement, and analyze common issues such as crossover distortion. This helps us understand the causes of distortion and explore possible solutions. Additionally, this experiment provides a more concrete understanding of power amplification concepts. In applications such as audio amplification or circuits requiring higher output current, the advantages of the push-pull configuration become particularly evident.

By completing this experiment, we gain hands-on experience in transistor applications and develop a foundational understanding of analog amplifier design.

II. Material Used

A. Resistors

220Ω*1, 470Ω*1, 680Ω*1, 1.2kΩ*1.5kΩ*1, 2.2kΩ*1, 4.7kΩ*1, 22kΩ*1, 33kΩ*1

B. Capacitors

100pF*1,10μF*1, 47μFΩ*1, 100μF*2, 470μF*1

C. Other Components

A1015*1 , C1815*1 , C1384*1, A684*1, 1N4007*2

III. Principle

A. Linear Amplification

1. A push-pull amplifier is composed of a pair of complementary transistors (NPN and PNP), which handle the positive and negative halves of the signal cycle, respectively.
2. When the input is positive, the NPN transistor conducts while the PNP transistor is off; when the input is negative, the PNP transistor conducts while the NPN transistor is off.
3. To reduce crossover distortion, a static bias is usually added in the design to keep the transistors slightly conducting even when there is no input signal, thereby improving the smoothness of the switching transition.

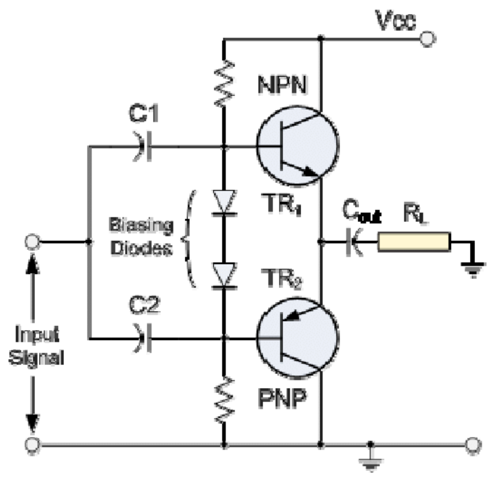
B. Static Bias and Crossover Distortion

1. When the input signal is close to 0V, both transistors may be in cutoff mode, causing a gap in the output waveform, which is known as crossover distortion.
2. Since there is no input signal, a continuous current flows through the amplifying

component, resulting in a lower efficiency for Class A amplifiers.

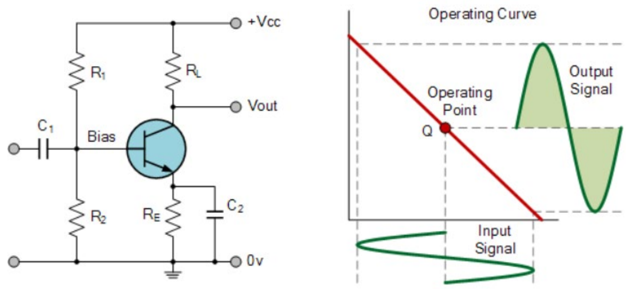
C. Efficiency and Heat Dissipation
   1. Since the two transistors conduct alternately, they do not conduct simultaneously, which helps reduce power loss and improve efficiency.
   2. Alternating operation also helps reduce the thermal burden on each transistor, thereby lowering the cooling requirements.

D. SEPP OTL Class AB power amplifier
   1. By combining the push-pull amplifier design with the Class AB operation mode, this design maintains high efficiency while effectively reducing crossover distortion, making it perform excellently in the audio amplification field.
   2. The Role of Diodes
      a. **Bias Current Setting**: The forward voltage drop of a diode (around 0.7V) is similar to the base-emitter voltage drop of a BJT. Therefore, diodes can be used to adjust the bias current of the two BJTs in a push-pull configuration, ensuring a slight overlap in their operation in Class AB mode, which helps reduce crossover distortion.
      b. **Thermal Stability**: Diodes and BJTs have similar thermal characteristics. As temperature changes, the forward voltage drop of both the diode and the BJT changes simultaneously, helping to automatically adjust the bias and reduce the impact of temperature fluctuations on the amplifier's performance.



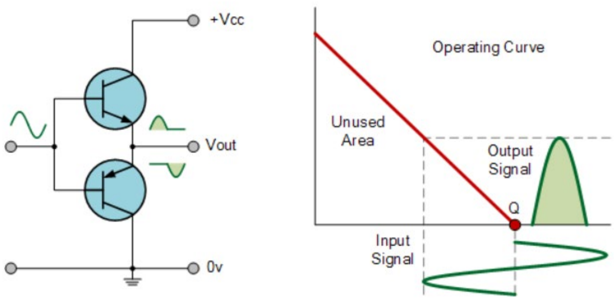
IV. Operating Points of Different Amplifiers

A. Class A Amplifier
   1. Advantages: High linearity, low distortion, and excellent sound quality.
   2. Disadvantages: Low efficiency (around 20-30%), high heat generation, and high power consumption.



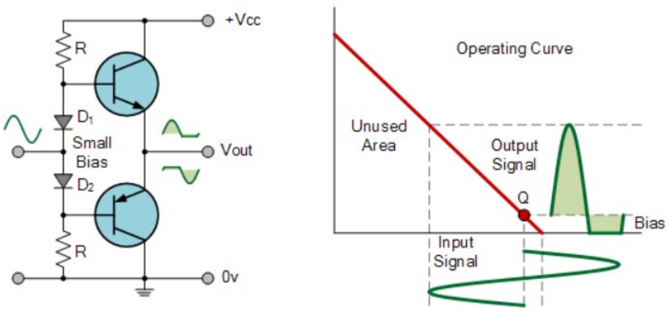
B. Class B Amplifier

1. Advantages: High efficiency (around 70–80%), less heat generation, and lower power consumption.
2. Disadvantages: Higher distortion, especially near the crossover point, resulting in slightly lower sound quality.



C. Class AB Amplifier

1. Advantages: High efficiency (around 50–70%), lower distortion, and better sound quality.
2. Disadvantages: Generates less heat than Class A amplifiers but slightly more than Class B amplifiers.



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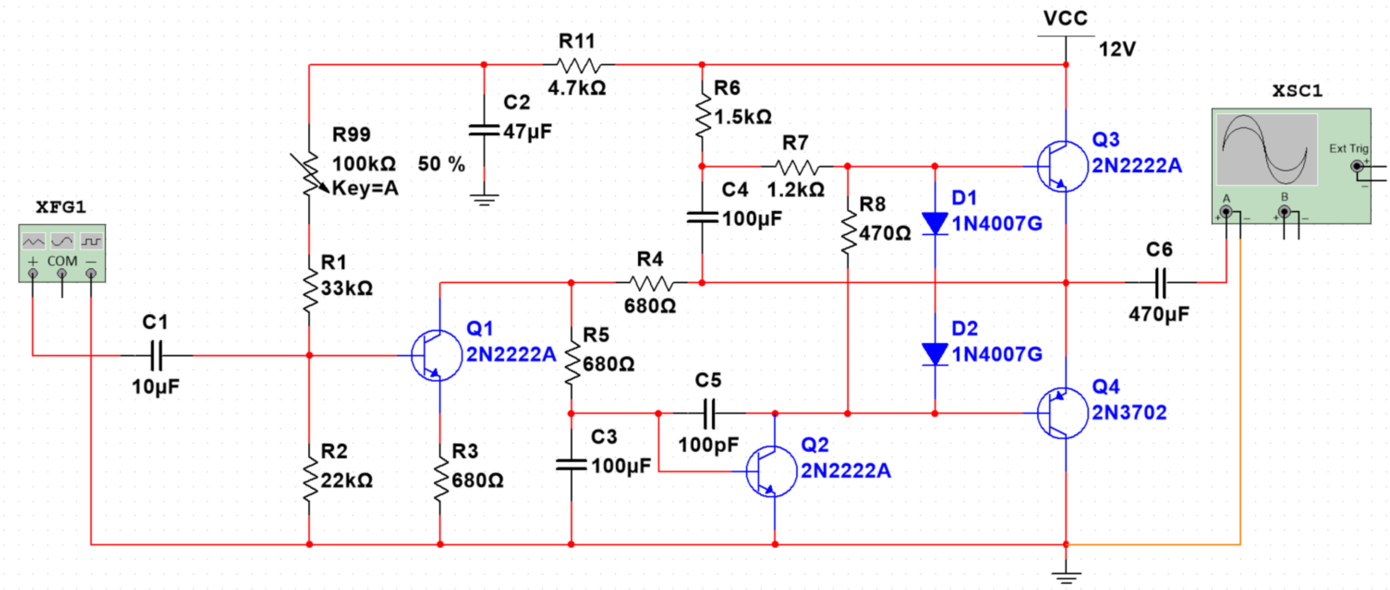
V. Circuit Diagram

A. Circuit Diagram



B. Partial Circuit Principles

1. Negative Feedback
   a. R4 and R5 form a voltage divider that feeds a portion of the output signal back to the emitter of Q1. This negative voltage feedback allows Q1 to compare the input signal with the output signal, generating an error signal that automatically adjusts the amplifier's gain, thereby improving stability and linearity.
   b. C3 is connected in parallel with R5 to bypass the AC signal, ensuring that only the DC biasing effect is maintained for feedback. This allows the AC gain to remain unaffected by excessive attenuation. It improves the frequency response for AC signals, ensuring stable operation even at low frequencies.
2. Bootstrap Circuit
   a. C4 (Bootstrap capacitor): When the output voltage rises, C4 stores charge and, as the output voltage increases, feeds part of the output voltage back to the base of Q3 through R6, R7, and R8. This allows the base of Q3 to exceed the voltage bias limit of the power supply, ensuring that the transistor can continue to conduct.
   b. R6, R7, and R8 work together to adjust the Bootstrap feedback current and the base bias, controlling the conduction region and stability.

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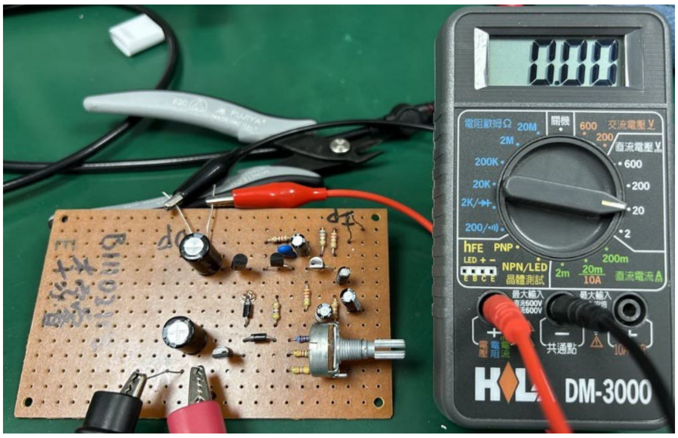
VI. Measurements

A. DC Test

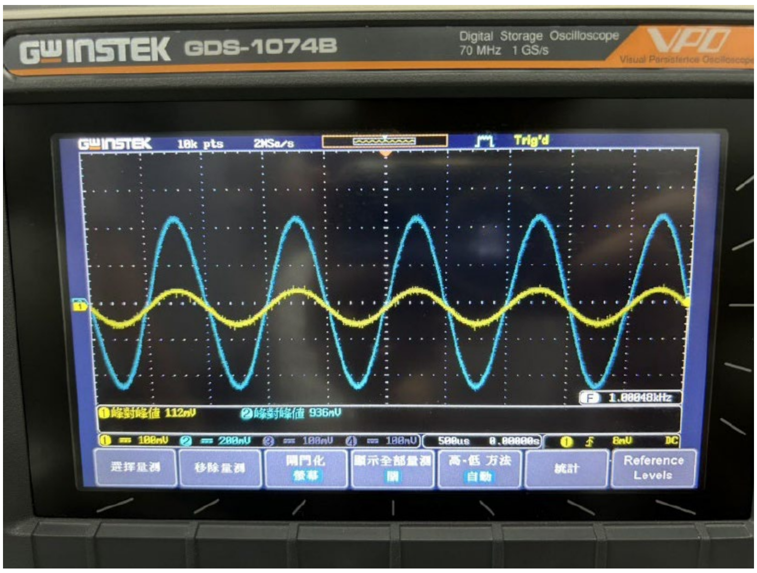
1. Midpoint Voltage Adjustment to 6V

2. DC Voltage Observation at Vo



B. AC Test

1. Check for Output at Dummy Load (CH2)



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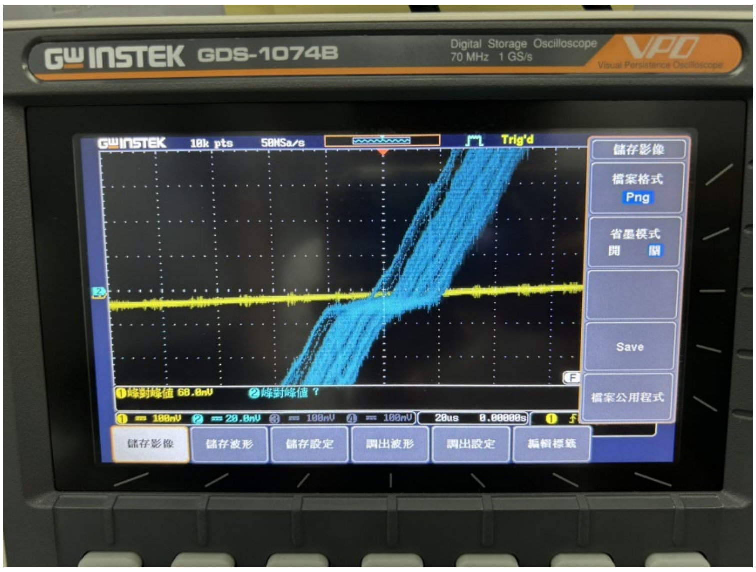
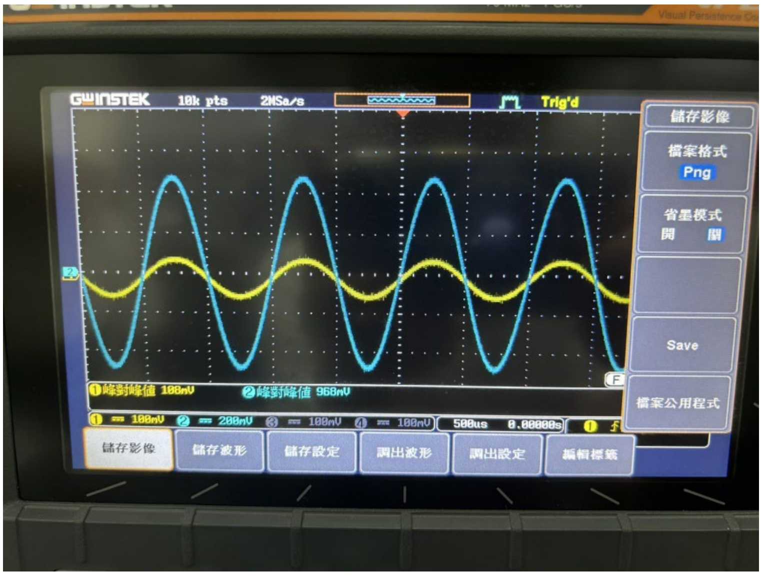
2. Set V_{in} for CH2 = 1 $V_{p\text{-}p}$; Observe Crossover Distortion



3. Voltage Gain Calculation



$$Voltage\ Gain = \frac{V_o}{V_i} = \frac{960mV}{108mV} = 8.89$$

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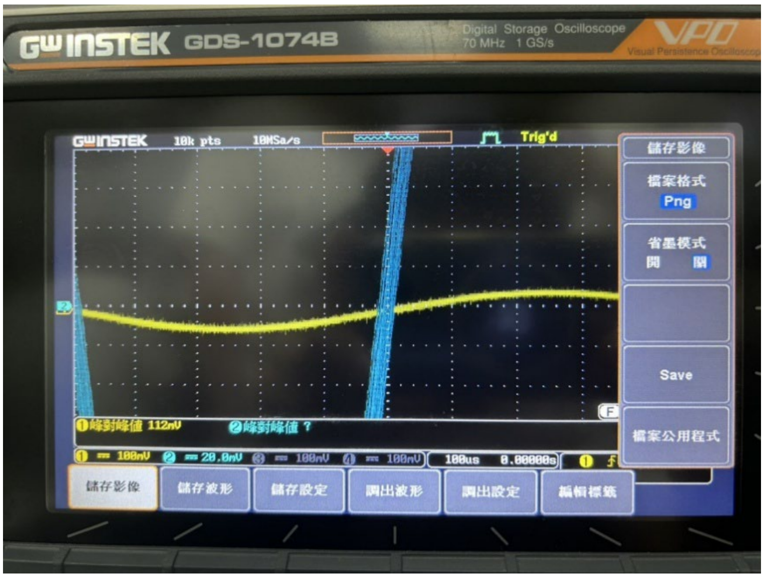
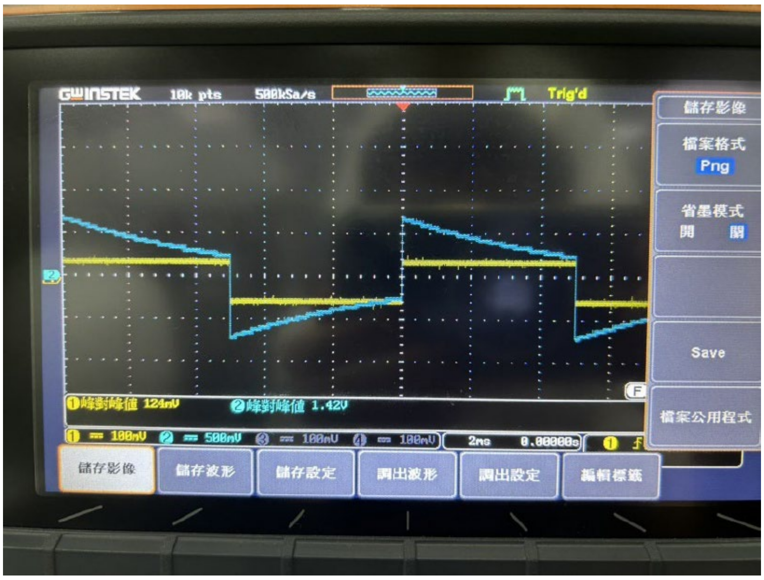
4. Observe Crossover Distortion

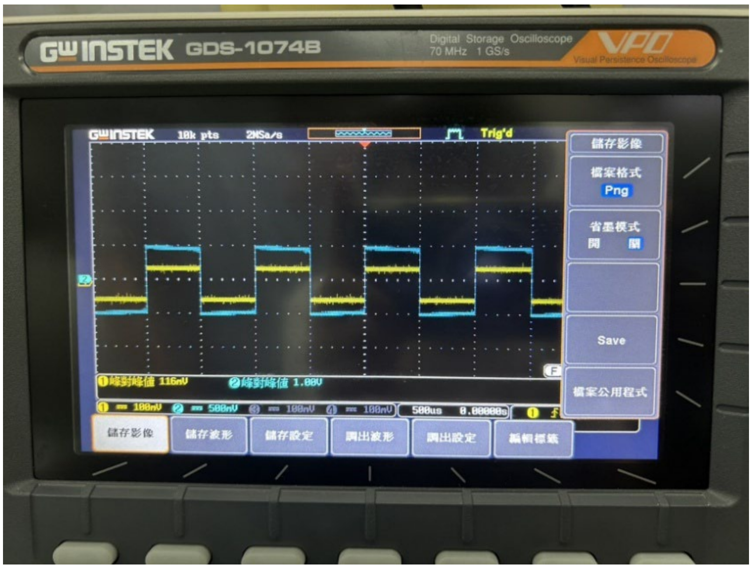


5. Square Wave Signal Testing

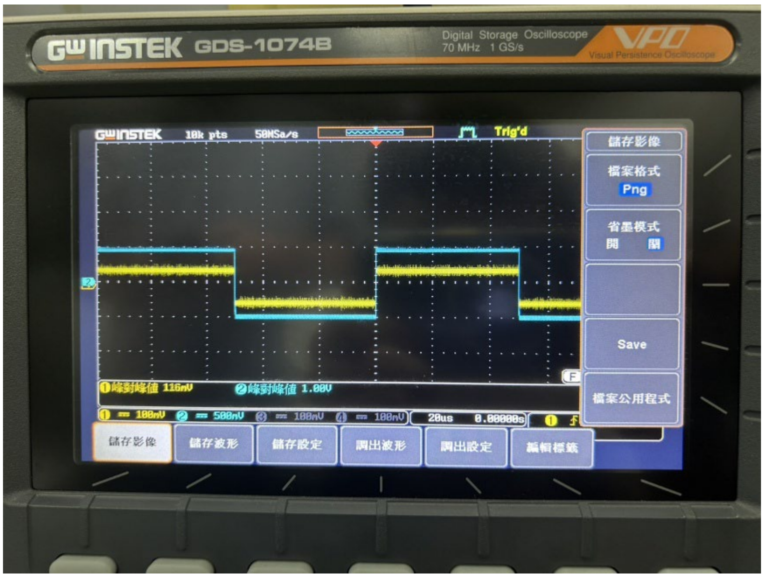
   a. 100Hz input



   b. 1KHz input

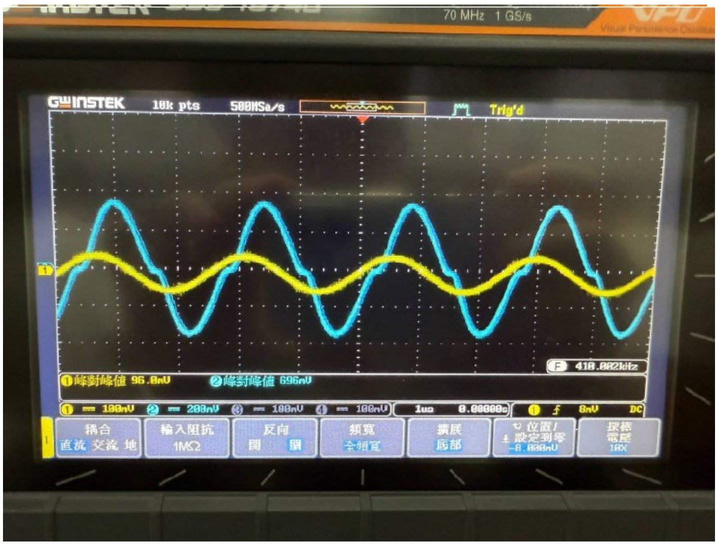


c. 10kHz input

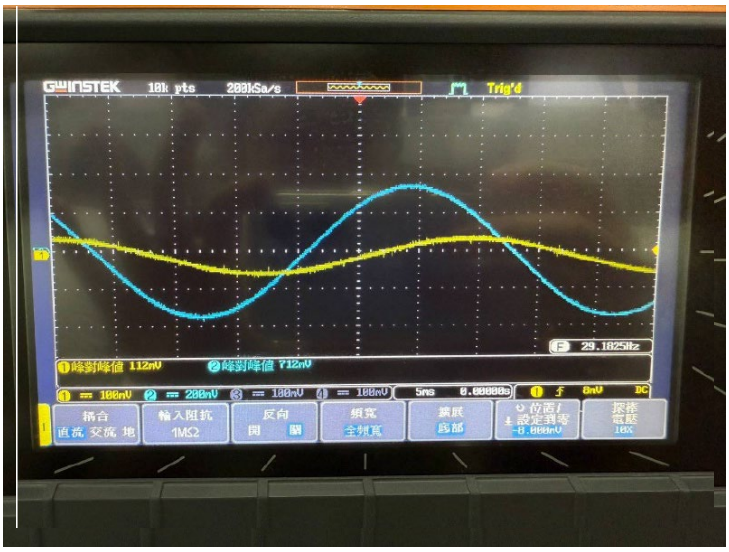


6. Find High and low-frequency cutoff points

   a. High-frequency cutoff point, f_c = 410 kHz

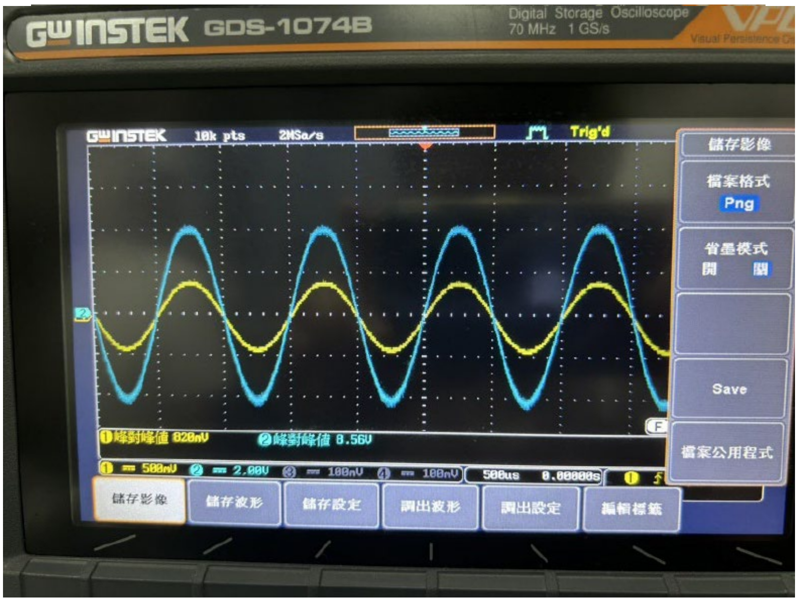


   b. Low-frequency cutoff point, f_c = 29 kHz



7. Find the maximum undistorted point

   a. Maximum $V_{p-p} = 8.56V$



   b. Output power

$$P_L = \frac{V_{o(peak)}^{\ \ 2}}{2R_L} = \frac{4.32^2}{13.6} = 1.366W$$

VII. Issues and Discussion

A. Why does crossover distortion occur in a push-pull output stage? How can it be improved using diodes?

1. Why does crossover distortion occur in the output?

   Crossover distortion mainly occurs in the push-pull output stage of Class A or Class AB amplifiers. When the signal transitions from the positive half-cycle to the negative half-cycle (or vice versa), complementary transistors (such as NPN and PNP) require a certain conduction voltage (approximately 0.6V). In the region where the input voltage is close to 0V, both transistors may not conduct at the same time, causing the output to fail to accurately follow the input signal, resulting in a flat region or distortion in the waveform. This range, where both transistors are not conducting, is called the "dead zone," and it is the main cause of crossover distortion.

2. Why does adding diodes help?

   The purpose of adding diodes in the output stage is to provide appropriate pre-biasing, allowing the complementary transistors to turn on slightly before the input signal crosses zero, thus reducing the dead zone. Typically, two silicon diodes are used, with a forward voltage drop of about 0.6 to 0.7V, which is close to the threshold voltage required for transistor conduction. This keeps the transistors in a near-threshold conducting state. Such a design allows for a smoother transition between the positive and negative halves of the output signal, effectively reducing crossover distortion.

B. Why does a low-frequency square wave cause the output edges to become sloped?

1. Why do the edges of the waveform become sloped at low frequencies?

   When inputting a square wave signal with a low frequency (e.g., 100Hz), the high-pass filter formed by the coupling capacitors and biasing resistors will attenuate the high-frequency components of the signal. This causes the edges of the waveform (rising/falling edges) to become slower, resulting in a "sloped" appearance. In this case, the amplifier cannot fully track the rapid changes of the square wave, leading to an output waveform that appears trapezoidal or tilted.

2. Why does the waveform return to normal at high frequencies?

   When the frequency increases to 1kHz or even 10kHz, the high-frequency components of the square wave are preserved, and the coupling capacitor can charge and discharge quickly. As a result, the rising and falling edges of the output waveform become more vertical, and the waveform gradually returns to the ideal square wave shape.

C. Why does crossover distortion occur at the high-frequency cutoff, but not at low frequencies?

1. Why does crossover distortion occur at high frequencies?

   At high frequencies (such as 400kHz), due to the rapid changes in the signal, the transistors cannot switch fast enough, making the dead zone effect more pronounced and resulting in more severe distortion.

2. Why is there no crossover distortion at low frequencies?

   At low frequencies (such as 29Hz), the signal changes slowly, giving the transistors in the amplifier enough time to switch between conducting and cutting off. As a result, the dead zone effect is relatively less pronounced, and the waveform appears smoother without noticeable crossover distortion.

VIII. Reflections

This AB class amplifier experiment was a very rewarding hands-on experience. Although we didn't design the circuit ourselves, each step—from component installation and signal testing to waveform observation—helped me gain a more concrete understanding of the amplifier's operating principles, especially regarding crossover distortion and methods for improvement.

At the beginning of the experiment, we shorted the diodes in the circuit and observed the output waveform. Around the zero-crossing point, we noticed small discontinuities, indicating the presence of crossover distortion. Then, we reconnected the diodes to the circuit, providing a bias voltage. Afterward, the waveform became smoother, and the contrast was quite clear, allowing me to practically experience the "dead zone" issue in AB class amplifiers and the effect of diodes in improving distortion.

The experiment went relatively smoothly, and there were no issues with soldering or contact in the circuit, allowing us to focus on observation and operation. Through the changes in the waveform and actual measurements, I gained a clear understanding of the circuit's behavior and also practiced how to use instruments to verify the circuit's operation.