1. Objective
This project will introduce two common power amplifier topologies, and also illustrate the difference between a Class-B and a Class-AB amplifier.

2. Components

<table>
<thead>
<tr>
<th>Qty</th>
<th>Device</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2N3904 NPN Transistor</td>
</tr>
<tr>
<td>1</td>
<td>2N3906 PNP Transistor</td>
</tr>
<tr>
<td>3</td>
<td>1N4001 Diode</td>
</tr>
</tbody>
</table>

3. Introduction
Up to this point, we have studied primarily small signal, linear amplifiers. These amplifiers are designed to maximize linearity (that is, reduce the magnitude of harmonics generated by the amplifier) at the expense of efficiency. While these amplifiers work well in many situations, it is often desirable to design an amplifier that is much more energy-efficient.

3.1 Class-B Amplifier
This lab introduces two amplifier topologies: The Class-B amplifier, and the Class-AB amplifier. The Class-B amplifier consists of two transistors in a push-pull configuration. Figure 1 shows a common configuration using a 2N3904 transistor and a 2N3906 transistor. When the amplifier is in its quiescent state, no current flows in the collector of either transistor, meaning that the transistors are off. When the input signal either raises the base to approximately 0.7V or falls below -0.7V from the quiescent point, then the upper or lower transistor turns on and begins to conduct. Since the transistors are in an emitter-follower configuration, the output voltage tracks the Vb base voltage less vbe.

It is important to note that because the transistors do not conduct until the input reaches 0.7V; some information is lost in the output signal, creating a crossover region in the output signal in which the output signal is zero.

3.2 Class-AB Amplifier
The Class-AB amplifier is an attempt to remove the nonlinearities generated by the Class-B amplifier while still maintaining its relatively high efficiency. This is done by adding two emitter resistors and three diodes (or diode-configured transistors) to force a voltage difference between the bases of the transistors. This keeps both transistors on with no input signal, but when an input signal is applied, the transistors alternate between on and off, thus increasing efficiency and delivering all of the emitter current above the quiescence current to the load.

Figure 2 shows the Class-AB amplifier schematic. Each diode has an on voltage of approximately 0.53V, giving a total base voltage separation of 1.59VDC. This is enough to turn both transistors on Vbe = 0.7VDC. Remember that when a large signal is applied, though, one transistor turns off and one remains on.
4. Requirements
The Class-B amplifier should meet the following requirements:

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load Power:</td>
<td>50 mW</td>
</tr>
<tr>
<td>Load Resistance:</td>
<td>220 Ω</td>
</tr>
<tr>
<td>$V_{BE}$</td>
<td>0.7 V$_{DC}$</td>
</tr>
<tr>
<td>Input Resistance:</td>
<td>Between 4 kΩ and 6 kΩ</td>
</tr>
<tr>
<td>Base Resistors</td>
<td>$R_{b1} = R_{b2}$</td>
</tr>
<tr>
<td>Low Frequency Cutoff</td>
<td>Between 100 Hz and 300 Hz</td>
</tr>
<tr>
<td>High Frequency Cutoff</td>
<td>Between 50 kHz and 200 kHz</td>
</tr>
<tr>
<td>Power Supply Voltage</td>
<td>Bipolar, ±12V$_{dc}$</td>
</tr>
</tbody>
</table>

Table 1. Class-B amplifier requirements.

The Class-AB amplifier should meet the following requirements:

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load Power:</td>
<td>50 mW</td>
</tr>
<tr>
<td>Load Resistance:</td>
<td>220 Ω</td>
</tr>
<tr>
<td>Collector Current:</td>
<td>4mA, quiescent</td>
</tr>
<tr>
<td>$V_{BE}$</td>
<td>0.7 V$_{DC}$</td>
</tr>
<tr>
<td>Diode voltage $V_D$:</td>
<td>0.53 V$_{DC}$</td>
</tr>
<tr>
<td>Input Resistance:</td>
<td>Between 4 kΩ and 6 kΩ</td>
</tr>
<tr>
<td>Low Frequency Cutoff</td>
<td>Between 100 Hz and 300 Hz</td>
</tr>
<tr>
<td>High Frequency Cutoff</td>
<td>Between 50 kHz and 200 kHz</td>
</tr>
<tr>
<td>Base Resistors</td>
<td>$R_{b1} = R_{b2}$</td>
</tr>
<tr>
<td>Emitter Resistors</td>
<td>$R_{e1} = R_{e2}$</td>
</tr>
<tr>
<td>Power Supply Voltage</td>
<td>Bipolar, ±12V$_{dc}$</td>
</tr>
</tbody>
</table>

Table 2. Class-AB amplifier requirements.

5. Prelab Design Project
You will design two amplifiers: a Class-B power amplifier, and a Class-AB power amplifier circuits shown in Figures 1 and 2 respectively. You should refer to your class notes, textbook, instructor, and other reference material to help you design the circuits. Start with the DC design and then move onto the AC design you will need to find the peak output $V_L$ and $I_L$. Use the following fixed component values in your circuit:

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_i$</td>
<td>150Ω</td>
</tr>
<tr>
<td>$C_{byp}$ (both supplies)</td>
<td>0.1µF, 0.047µF, or 0.01µF</td>
</tr>
</tbody>
</table>

Table 3. Fixed component values.
Figure 1. Class-B Power Amplifier.

Figure 2. Class-AB Power Amplifier.
5.1 DC Bias
Begin by designing the base resistors for the Class-B amplifier. The two resistors should be equal, so that with no input signal both transistors are off. It may help to use symmetry in the circuit and look only at one half with the output voltage at the peak value. The other half be a mirror image.

The **maximum** value of the **base resistors** dictated by the maximum peak base current required and $V_{BE} = 0.7V_{DC}$. Based on the power requirement, determine the maximum peak base current (assume a worst-case **Beta value of 100** here) and the minimum voltage drop across the base resistors. The combination of these values will set the maximum resistor values. The minimum values are set by the input resistance specification. Remember that you are using a bipolar ($\pm 12V$) power supply. Read the schematic carefully.

For the **Class-AB** amplifier, you will need to perform a similar procedure. Since the diodes are forward-biased in all cases, simply treat them as ideal voltage sources equal to 0.53V and $V_{BE} = 0.7V_{DC}$. This creates a potential between the transistor bases. Use symmetry to divide the circuit and write equations to determine $R_e$ and $R_b$ evaluate at $V_{out}$ peak. Ensure that the voltage at the output is at 0V, or as close as you can get it. Once again, when calculating the base and emitter resistors, assume the worst-case **Beta value of 100**.

Note that there is no single correct answer and that your design may differ significantly from your colleagues’. You should show all work and walk through all calculations. You must calculate and show all of the following values for both amplifiers (as needed).

<table>
<thead>
<tr>
<th>Component Values</th>
<th>Amplifier Parameters</th>
<th>Voltages and Currents</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{b_1}$</td>
<td>Beta dc</td>
<td>$V_{ce}$</td>
</tr>
<tr>
<td>$R_{b_2}$</td>
<td>Beta ac</td>
<td>$V_{be}$</td>
</tr>
<tr>
<td>$R_{e_1}$ (Class-AB)</td>
<td>$r_{\pi}$</td>
<td>$V_{be}$</td>
</tr>
<tr>
<td>$R_{e_2}$ (Class-AB)</td>
<td>$r_o$</td>
<td>$V_{e}$</td>
</tr>
</tbody>
</table>

Table 4. DC Bias and Amplifier Parameters

5.2 AC Design
Design the ac characteristics of the amplifiers. **All calculations are at Vout peak**. You must calculate and show all of the following values. $C_{in}$ is given for the class B. Must be found for the class AB.

<table>
<thead>
<tr>
<th>Component Values</th>
<th>Amplifier Parameters</th>
<th>Voltages, Currents, and Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{in}$</td>
<td>Voltage Gain</td>
<td>$V_{in}$</td>
</tr>
<tr>
<td>$C_{ni}$</td>
<td>Current Gain</td>
<td>$v_{out}$</td>
</tr>
<tr>
<td></td>
<td>Power Gain (in dB)</td>
<td>$i_{in}$</td>
</tr>
<tr>
<td></td>
<td>Low Frequency Cutoff</td>
<td>$I_{out}$</td>
</tr>
<tr>
<td></td>
<td>High Frequency Cutoff</td>
<td>$P_{in}$</td>
</tr>
<tr>
<td></td>
<td>Input Resistance</td>
<td>$P_{out}$</td>
</tr>
<tr>
<td></td>
<td>Output Resistance</td>
<td></td>
</tr>
</tbody>
</table>

Table 5. Small Signal (AC) amplifier Parameters
5.5 Computer-aided Analysis Class B, Class AB

Once you have completed your two amplifier designs, use LTspice to analyze their performance, and **include the LTspice schematics.** Use the 1N4002 diodes. Generate the following plots:

(a) A time-domain plot (waveform) of the input and output, adjust the input such that the required output is obtained. The output should not have any distortion or clipping for the Class-AB amplifier. Calculate the midband gain and indicate it on the plot. Compare this to your calculated values.

(b) An FFT of your time-domain waveform. Circle and indicate the height of any strong harmonics, in dB relative to your fundamental frequency.

(c) A frequency sweep of the amplifier (the **plot of class B will look different**) from 10 Hz to 1 MHz. Indicate the high and low frequencies on the plot (these should correspond to the half-power, or -3dB points). Compare these to your calculated values.

Note: if you amp is oscillating make sure the bypass capacitors are in place, and add a 220pf capacitor to the base of each BJT to ground.

6.1. Construct the Class-B amplifier shown in Figure 1. Remember that the 50Ω resistor is internal to the function generator and is not in your circuit. Record the values of the bias network resistors and the capacitors you used in the circuit. If your Class B has noise on the output, bypass the collectors of the BJTs. If it still has, noise put a .001uF capacitor on the output to ground.

6.2. Measure the following values:
(a) Voltage, current, and power gains use Vin= 10Vpp at 5kHz.
(b) Maximum undistorted peak-to-peak output voltage.
(c) Input and output resistance.
(d) Output power.
(e) Threshold (turn-on) voltage.

Recall that input impedance is given by $R_{in} = \frac{v_{in}}{i_{in}}$, output impedance is given by $R_{out} = \frac{(v_{oc}-v_{load})}{i_{load}}$, voltage gain is given by $A_v = \frac{v_{out}}{v_{in}}$, and current gain is given by $A_i = \frac{i_{load}}{i_{in}}$.

Additionally, plot the following:
(a) Input and output waveform.
(b) FFT showing the fundamental frequency and first few harmonics.
(c) Frequency response from 10 Hz to 1 MHz (set the input voltage to a value that does not cause distortion across the entire passband of the amplifier).

6.3. Construct the Class-AB amplifier shown in Figure 2. Remember that the 50Ω resistor is internal to the function generator and is not in your circuit Record the values of the bias network resistors and the capacitors you used in the circuit. Use the 1N4001 diodes.

6.4. Measure the following values:
(a) Q-points: $V_{ce}, V_{be}, V_E, V_C, V_B$ and $I_C$, and.
(b) Voltage, current, and power gains use Vin= 10Vpp at 5kHz.
(c) Maximum undistorted peak-to-peak output voltage.
(d) Input and output resistance.
(e) Low and high cutoff frequencies (half power point).
(f) Output power.

Recall that input impedance is given by $R_{in} = \frac{v_{in}}{i_{in}}$, output impedance is given by $R_{out} = \frac{(v_{oc}-v_{load})}{i_{load}}$, voltage gain is given by $A_v = \frac{v_{out}}{v_{in}}$, and current gain is given by $A_i = \frac{i_{load}}{i_{in}}$.

Additionally, plot the following:
(a) Input and output waveform at the maximum undistorted value.
(b) FFT showing the fundamental and first few harmonics.
(c) Frequency response from 10 Hz to 1 MHz (set the input voltage to a value that does not cause distortion across the entire passband of the amplifier).
6.1. Component values for class-B power amplifier.

\[ R_{b1}: \quad R_{b2}: \quad R_L: \]

6.2. Class-B power amplifier. \textbf{Do Not} connect the load resistor until you verify the Q-point and the output voltage is \( \approx 0\text{Vdc} \). There are three printouts here.

\begin{center}
\begin{tabular}{|l|l|l|}
\hline
Capacitor Value: & \( C_{in} \): \\
\hline
Vin=10Vpp @ 5kHz Gain: & Voltage: \\
\hline
Voltage Output Swing: & Max: \\
\hline
Resistance: & Input: \\
\hline
Output Power: & \( P_{RMS} \): \\
\hline
Threshold Voltage: & \( V_{TH} \): \\
\hline
\end{tabular}
\end{center}

6.3. Component values for class-AB power amplifier.

\[ R_{b1}: \quad R_{b2}: \quad R_L: \]
\[ R_{e1}: \quad R_{e2}: \]

6.4. Class-AB power amplifier. \textbf{Do Not} connect the load resistor until you verify the Q-point and the output voltage is \( \approx 0\text{Vdc} \). There are three printouts here.

\begin{center}
\begin{tabular}{|l|l|l|}
\hline
Capacitor Values: & \( C_{in} \): \\
\hline
Q-Point (Q1): & \( V_{ce} \): \\
\hline
\( V_B \): & \( I_C \): \\
\hline
\( V_{BE} \): & \( V_E \): \\
\hline
\( V_C \): & \\
\hline
Q-Point (Q2): & \( V_{ce} \): \\
\hline
\( V_B \): & \( I_C \): \\
\hline
\( V_{BE} \): & \( V_E \): \\
\hline
\( V_C \): & \\
\hline
Vin= 10Vpp @ 5kHz Gain: & Voltage: \\
\hline
Voltage Output Swing: & Max: \\
\hline
Resistance: & Input: \\
\hline
Frequency Response: & Low: \\
\hline
Output Power: & \( P_{RMS} \): \\
\hline
\end{tabular}
\end{center}