12.0 Power Amplifiers

(a) Power supply level
   Full 360° output swing
   Class A dc bias level
   0 V
   t

(b) Class B dc bias level
   180° output swing
   0 V
   t
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Class A Power Calculations

\[ \text{Pi}(dc) = Vcc \times Ico } \]

\[ \text{Po}(ac) = Ic_{rms}^2 \times Rc } \]

\[ = \left(\frac{I_p}{2^\frac{1}{2}}\right)^2 \times Rc \]

\[ = \left(\frac{Vc}{2^\frac{1}{2}}\right)^2 \times Rc \]

\[ = \left(\frac{V_{cpp}}{2 \times 2^\frac{1}{2}}\right)^2 \times Rc \]

\[ = \left(\frac{V_{cpp}}{8Rc}\right)^2 \]

\[ = \left(\frac{I_{cpp}}{8Rc}\right) \times 2^\frac{1}{2} \times Rc \]

\[ = \left(\frac{V_{cpp}}{8Rc}\right)^2 \times Rc \]

and since,

\[ V_{cpp} = I_{cpp} \times Rc \]

then,

\[ \text{Po}(ac) = V_{cpp} \times I_{cpp} / 8 \]
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Maximum Power Output and Efficiency

If the max output voltage swing is,

\[ V_{c_{pp}}^{\text{max}} = V_{cc} \]

and then,

\[ P_{o_{\text{max}(ac)}} = \frac{(V_{cc})^2}{8R_c} \]

In order for this to be true the bias situation is that

\[ V_{CQ} = \frac{V_{cc}}{2} \]

and therefore,

\[ I_{CQ} = \frac{V_{cc}}{2R_c} \]

Power input to the circuit is then,

\[ P_{i_{\text{max}(dc)}} = \frac{V_{cc} \cdot V_{cc}}{2R_c} \]

The efficiency is then,

\[ \% = \frac{P_{o_{\text{max}(ac)}}}{P_{i_{\text{max}(dc)}}} = 25\% \]

But, if the bias is not in the center, the power output is as calculated as

\[ P_{o_{(ac)}} = \frac{V_{c_{pp}} \cdot I_{c_{pp}}}{8} \]

and

\[ P_{i_{(dc)}} = V_{cc} \cdot I_{co} \]
The Class A amplifier has a load line and Q-point as shown. Determine the power situation.

a) What is the $\Pi$?
b) What is the maximum $P_o$ when the amp is operated at this Q-point?
\[ P_i = VCC \times I_CQ = 20V \times 2mA = 40mW \]
\[ P_o = \frac{V_{rms}^2}{R} \quad R = \frac{20}{8mA} = 2500 \]
\[ = \frac{(5/2^{0.5})^2}{2500} = 5mW \] or,
\[ P_o = \frac{(V_{cemax} - V_{cemin})(I_{cmax} - I_{cmin})}{8} \]
\[ = \frac{(20-10)(4 - )}{8} = 5mW \]
c) What is the maximum $P_o$ when the amp is operated at a Q-point of 10v and 4ma?
\[ P_o = \frac{(20 - 0)(8 - 0)}{8} = 20mW \] and \[ P_i = 20V \times 4mA = 80mW \]
For the circuit below determine,

\[ V_{AMPL} = 4\text{m} \]

a) \( P_i(df) \), ignore the base current
\[ P_i = 20V \times 10.7mA = 0.214W \]

b) \( P_o(ac) \)
\[ P_o = \frac{(10.6 - 7.8)^2}{1k} = 0.952\text{mW} \]
\[ (\frac{2\times21}{2})^2 \]
The collector-emitter voltage swing is,
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(a)\[ \frac{V_2}{V_1} = \frac{N_2}{N_1} \]

(b)\[ \frac{I_2}{I_1} = \frac{N_1}{N_2} \]

(c)\[ R'_L = a^2 R_L = \left(\frac{N_1}{N_2}\right)^2 R_L \]
The signal output swing is nearly 2x the supply voltage. This is the efficiency improvement.
Class A Transformer Power Calculations

\[ V_{CEpp} = V_{CEmax} - V_{CEmin} \]

\[ I_{Cpp} = I_{Cmax} - I_{cmin} \]

\[ P_{o(ac)} = \frac{(V_{CEmax} - V_{CEmin})(I_{Cmax} - I_{cmin})}{8} \]

Efficiency of amplifier

\[ P_{i(dc)} = V_{cc}I_{CQ} \]

\[ \% \text{ efficiency} = 50 \times \left(\frac{V_{CEmax} - V_{CEmin}}{V_{CEmax} + V_{CEmin}}\right)^2 \]

If \( V_{CEmin} = 0 \), then efficiency is max at 50\%
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$V_{CC} = 10 \text{ V}$

$R_1$

$V_i$

$C$

$I_B = 6 \text{ mA}$

$R_2$

Due to $V_i$:

$I_{b_{peak}} = 4 \text{ mA}$

$V_1$

$V_L$

$R_L = 8 \Omega$

$N_1 / N_2 = 3:1$

$R_E$

$C_E$
\[ I_B = 6\text{mA} \quad \text{&} \quad I_b \text{ p-p} = 8\text{mA}, \text{ swing of } +4\text{mA} \]

for \( N_1/N_2 = 3 \quad \text{&} \quad RL = 8 \quad \text{RL’} = 72 \text{ ohms} \)

Then the slope of \(1/72\) gives an intersection of current axis at,

\[ I_c = 140\text{mA} + \frac{10V}{72} = 140\text{mA} + 139\text{mA} = 279\text{mA} \]

Looking at the graph & setting the max \( I_b = 6\text{mA} + 4\text{mA} = 10\text{mA} \)........results in a max of 255mA by eyeballing the plot.

The minimum current is when \( I_b = 6\text{mA} – 4\text{mA} = 2\text{mA} \) \quad \text{and is} \quad 25\text{mA} \text{ again from estimating the plot.}

from the plot the min and max \( V_{ce} \)’s are found to be \( 1.7V \text{ and } 18.3V \).

Notice that the signal swing is nearly 2X the supply voltage.....this where the efficiency gain occurs. So, the power output is,

\[ P_{o(ac)} = (18.3 – 1.7)(255\text{mA} – 25\text{mA})/8 = 0.477W \]

\[ P_{i(dc)} = V_{cc} \times I_{cq} = 10\text{V} \times 140\text{mA} = 1.4W \]

& the efficiency is \( 0.477/1.4 = 34.1\% \)

The max for a class A transformer coupled amp is 50\%. 

The resistance load of a transistor amplifier is plotted on the transistor characteristics. Determine,
a) Input power, $P_{dc}$
b) Maximum output power

\[ P_{dc} = (160 \text{mA})(25) = 4 \text{ W} \]
\[ R = \frac{25}{0.4} = 62.5 \text{ ohms} \]
\[ P_{ac} = \frac{V_p^2}{2R} = \frac{(25-15)^2}{2 \times 62.5} = 0.8 \text{ W} \]
The load reflected back to the transistor is 50 ohms. Determine the following,

a) Load line
b) Minimum and maximum output voltages
c) Maximum power efficiency for this bias condition
\[
\text{eff} = 50\% (V_{\text{CEmax}} - V_{\text{C Emin}})(V_{\text{CEmax}} + V_{\text{C Emin}})/8 \\
= 50\%[(17.5 - 2.5)/(17.5 + 2.5)]^2 \\
= 28.125\%
\]
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For the transformer-coupled Class A amplifier below the dc base current is 6ma and the signal base current swings from 8ma to 4ma. The turns ratio is 5:1 and the load resistance is 4 ohms.

a) Find and plot the Q-point on the collector characteristics below.
12V & 180mA 5pt

b) What is the input power including both the base and collector currents?
\[(180+6)\times10 = 1860\text{mW} = 1.86\text{W}\] 5pt

c) What is the power delivered to the load?
\[\text{PL} \approx \frac{1}{8} \times (18 - 7) \times (240\text{mA} - 125\text{mA}) = 0.18\text{W}\] 5pt

Loadline 100 5pt
The Class A transformer-coupled power amplifier circuit schematic and simulation results are given below. The schematic with DC collector current is,

Q1 collector voltage waveform is,
The collector current waveform is,
4 ohm resistor voltage waveform is,

Determine the following,

a) $P_i(\text{dc})$ ignore the base current
   \[ P_i = 20V \times 55.58mA = W \]

b) $P_o(\text{ac})$ using the collector voltage & current waveform values.
   \[ P_o = \frac{1}{8}(21.5V - 18.4V) \times (61.8mA - 49.8mA) = W \]

c) $P_o(\text{ac})$ using the load voltage waveform values (show calculations).
   \[ P_o = \sqrt{\frac{((200mV + 185mV)/2)^2}{4}} \]
Assume the power amplifiers in the questions below are operating at a Q-point such that maximum power output could be obtained if desired.

Determine for each power amplifier circuit the following,

a) Power Input
b) Power Output

Show your work; i.e., the formulas/algebra you used for each problem.

1. A resistor-load power amplifier has a voltage output swing peak voltage equal to 0.4Vcc.

\[ P_i = Vcc * \frac{Vcc}{2R} = \frac{Vcc^2}{2R} \]
\[ P_o = \frac{(0.4Vcc/(2^{1/2}))^2}{R} \]

2. A 1:1 transformer-load power amplifier has a voltage output swing peak voltage equal to 0.8Vcc.

\[ P_i = Vcc * \frac{Vcc}{R} = \frac{Vcc^2}{R} \]
\[ P_o = \frac{(0.8Vcc/2^{1/2})^2}{R} \]

3. A Class B (push-pull) power amplifier has a voltage output swing peak voltage equal to 0.7Vcc.

\[ P_i = Vcc * 2(0.7)Vcc/\pi R \]
\[ P_o = \frac{(0.7Vcc/2^{1/2})^2}{R} \]
Class B amplifier - eliminate the bias current.
Class B Power Calculations

Input Power \( = Pi(dc) = Vcc \cdot Idc \)

For each half cycle current goes through the power supply, \( Vcc \).

For a half wave rectifier the average current is,
\( Idc = Ip/\pi \)

and since this current flows on each half cycle the average current is
\( Idc = 2Ip/\pi \)

\[ = 2 \cdot \frac{V_{Lp}}{R_L} \pi \]

\[ Pi(dc) = 2 \cdot Vcc \cdot \frac{V_{Lp}}{R_L} \pi \]

Output Power
\( Po(ac) = V_{Lrms}^2/R_L \)

\[ = V_{Lp}^2/2R_L \]

\[ = V_{Lpp}^2/8R_L \]
Efficiency

\[ \% = 100\% \times \frac{P_{o(ac)}}{P_{i(dc)}} \]

\[ = 100\% \times \left( \frac{V_{Lp}^2}{2R_L} \right) / \left( 2 \times \frac{V_{Lp}}{R_L} \pi \right) \]

\[ = 100\% \times \pi \times \left( \frac{V_{Lp}}{4V_{cc}} \right) \]

and if \( V_{Lp} = V_{cc}/2 \) then

\[ \% = \frac{\pi}{4} = 78.5\% \]

Transistor Power

\[ P_{2Q} = P_{i(dc)} - P_{o(ac)} \]

\[ P_{Q} = \frac{1}{2} \times P_{2Q} \]
Resistor Load
\[ P_i = V_{cc} \times \frac{V_{cc}}{2R} = \frac{V_{cc}^2}{2R} \]
\[ P_o = \frac{(V_{cc}/(2^{1/2}))^2}{2R} = \frac{V_{cc}^2}{8R} \]
%efficiency max = 25%

Transformer Load 1:1 turns ratio
\[ P_i = V_{cc} \times \frac{V_{cc}}{R} = \frac{V_{cc}^2}{R} \]
\[ P_o = \frac{(V_{cc}/2^{1/2})^2}{R} = \frac{V_{cc}^2}{2R} \]
%efficiency max = 50%

Push-Pull
\[ P_i = 2V_{cc} \times \frac{V_{cc}}{\pi R} \]
\[ P_o = \frac{(V_{cc}/(2^{1/2}))^2}{2R} = \frac{V_{cc}^2}{2R} \]
%efficiency max = \( \frac{1/2}{(2/\pi)} = 25\pi \% \)
Summary of Power Amplifiers

Draw 3 circuits

Output power - voltage and current
Signal swing (peak-to-peak / 2)/sqrt of 2 for rms
Ipp*Vpp/8

Input power Average Current*Average Voltage Supply

<table>
<thead>
<tr>
<th>Class</th>
<th>Vpp</th>
<th>Ipp</th>
<th>Output Power</th>
<th>Avg Current</th>
<th>Voltage Supply</th>
<th>Input Power</th>
<th>%efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class A</td>
<td>Vcc</td>
<td>Vcc/R</td>
<td>Vcc^2/8R</td>
<td>Vcc/2R</td>
<td>Vcc</td>
<td>Vcc^2/2R</td>
<td>25</td>
</tr>
<tr>
<td>Class A Transformer</td>
<td>2Vcc</td>
<td>2Vcc/R’</td>
<td>4Vcc^2/8R’</td>
<td>Vcc/R</td>
<td>Vcc</td>
<td>Vcc^2/R’</td>
<td>50</td>
</tr>
<tr>
<td>Class B</td>
<td>2Vcc</td>
<td>2Vcc/R</td>
<td>4Vcc^2/8R</td>
<td>2Vcc/πR</td>
<td>Vcc</td>
<td>2Vcc^2/πR</td>
<td>100π/4</td>
</tr>
</tbody>
</table>
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Amplifier Distortion

Harmonic Distortion

\[\% \text{ nth harmonic distortion} = \% \ D_n \quad \text{where} \quad n = 2, 3, 4, \ldots \ldots\]

\[= 100\% \* \frac{|A_n|}{|A_1|}\]

\[\% \ \text{THD} = \text{square root of sum of squares of } D_n\]

Power of Signal Having Distortion

\[P_1 = I_1^2 \* \frac{R_c}{2}\]

\[P = (I_1^2 + I_2^2 + I_2^2 + \ldots.) \* \frac{R_c}{2}\]

\[= (1 + \text{THD}^2) \* P_1\]
$P_T = \text{maximum total device dissipation (W)}$

![Graph showing the relationship between case temperature (°C) and maximum total device dissipation (W). The graph indicates a linear decrease in dissipation as the case temperature increases from 0°C to 200°C, with the dissipation remaining constant at 100 W between 0°C and 75°C.]
\[ \theta_{JA} = \theta_{JC} + \theta_{JS} + \theta_{SA} \]
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