Electronics Homework Set #2

Problem 1.29

A certain power amplifier supplies a 20 V peak 100 Hz sine wave to an 8-Ω load resistance as illustrated in the figure below. The currents supplied by the power supplies are half-sinusoid pulses, as shown in the figure. Find the average current for each supply, the average power supplied by each source, and the efficiency of the amplifier.

- The average current and power for each supply is:

  period = .01;

  \[
  \text{rmsAverageCurrent} = \sqrt{\frac{1}{\text{period}} \int_0^{\text{period}/2} (2.5 \sin(200 \pi t))^2 \, dt} ;
  \]

  voltage = 25.; averagePower = rmsAverageCurrent * voltage;
  Print["Average current = ", rmsAverageCurrent, " Ampere"]
  Print["Average supply power (each supply) = ", averagePower, " Watt"]

Average current = 1.25 Ampere

Average supply power (each supply) = 31.25 Watt
The output power is given by:

\[
\text{rmsOutputVoltage} = 20. \sqrt{2}; \quad \text{loadResistance} = 8; \\
\text{outputPower} = \frac{\text{rmsOutputVoltage}^2}{\text{loadResistance}}; \quad \text{Print["Average output power = ", outputPower, " Watt"]}
\]

Average output power = 25. Watt

- The efficiency is:

\[
\text{Efficiency} = \frac{\text{outputPower}}{2 \times \text{averagePower}} \times 100, \quad \%
\]

Efficiency = 40.%

**Problem 1.31**

An amplifier has an input voltage of 10 mV rms and an output voltage of 5 V across a 10- \( \Omega \) load. The input current is 1 \( \mu \)A rms. Assume that the input and output impedances are purely resistive. Find the input resistance. Find the voltage gain, the current gain, and the power gain as ratios and in decibels.

- Solution: The input resistance is 10 mV/1 \( \mu \)A = 10,000 \( \Omega \)

  Voltage Gain = 5V / 10 mV = 500.
  The output current is given by 5V / 10 \( \Omega \) = 0.5 A;
  so the current gain is \( A_i = 0.5 \text{A}/1 \mu \text{A} = 500,000 \)
  The power gain is \( G = A_v A_i = 2.5 \times 10^8 \)

\[
A_v = 5 / .01; \\
\text{dAv} = 20 \log[10, A_v]; \quad \text{Print["Voltage Gain = ", A_v, " \rightarrow ", dAv, " dB"]}
\]

Voltage Gain = 500. \( \rightarrow \) 53.9794 dB

\[
A_i = .5 / (1 \times 10^{-6}); \quad \text{dAi} = 20 \log[10, A_i]; \quad \text{Print["Current Gain = ", A_i, " \rightarrow ", dAi, " dB"]}
\]

Current Gain = 500,000. \( \rightarrow \) 113.979 dB

\[
G = A_v A_i; \quad \text{dG} = 10 \log[10, G]; \quad \text{Print["Power Gain = ", G, " \rightarrow ", dG, " dB"]}
\]

Power Gain = 2.5 \times 10^8 \( \rightarrow \) 83.9794 dB
Problem 1.37

An amplifier has an input resistance of 20 Ω, an output resistance of 10 Ω, and a short-circuit current gain of 3000. The signal source has an internal voltage of 100 mV rms and an internal impedance of 200 Ω. The amplifier load is a 5 Ω resistance. Find the current gain, voltage gain and power gain of the amplifier. If the power supply has a voltage of 12 V and supplies an average current of 2 A, find the power dissipated in the amplifier.

Solution:

```plaintext
Rin = 20.; Ro = 10.; Rs = 200.; RL = 5.;
Vs = .100; Vsupply = 12.; Isupply = 2.; Aisc = 3000.;

Iin = __________; Print["Input Current = ", Iin]
    Vs
    Rs + Rin

Iout = Aisc * Iin * __________; Print["Output Current = ", Iout]
    Ro
    Ro + RL

Ai = __________; Print["Current Gain = ", Ai]
    Iin

Input Current = 0.000454545
Output Current = 0.909091
Current Gain = 2000.

Vin = Iin * Rin; Print["Input Voltage = ", Vin, " Volt"]
Vout = Iout * RL; Print["Output Voltage = ", Vout, " Volt"]

Av = __________; Print["Voltage Gain = ", Av]
     Vin

Input Voltage = 0.00909091 Volt
Output Voltage = 4.54545 Volt
Voltage Gain = 500.

G = Av * Ai; Print["Power Gain = ", G]

Power Gain = 1. × 10^6

Vout^2
Pout = __________; Print["Output Power = ", Pout, " Watt"]
     RL

Vin^2
Pin = __________; Print["Input Power = ", Pin, " Watt"]
     Rin

Output Power = 4.13223 Watt

Input Power = 4.13223 × 10^-6 Watt

Psupply = Vsupply * Isupply; Print["Supply Power = ", Psupply, " Watt"]
Pdissipated = Psupply + Pin - Pout; Print["Power Dissipated = ", Pdissipated, " Watt"]

Supply Power = 24. Watt
Power Dissipated = 19.8678 Watt
```
Problem D1.49

Block Diagram Level Amplifier Design. An amplifier is needed for the documentation of voltages in the Earth created by a Navy extremely low frequency (ELF) antenna in northern Michigan (used for communication with submarines). Voltage waveforms occurring between probes to be placed in the earth are to be amplified before being applied to the analog-to-digital converter (ADC) inputs of small computers. The internal impedance of the probe can be as high as 10 kΩ in dry sand or as low as 10 Ω in muck. Because several different models of ADC’s are to be used in the project, the load impedance for the amplifier varies from 10 kΩ to 1 MΩ. Nominally the voltage applied to the ADC should be 10 times the voltage applied to the probe ±3%. What type of ideal amplifier is best suited for this application? Use your best judgment, and state what are the specifications for the impedances and gain parameter of the amplifier.
1. Consider whether zero or infinite input resistance would be best for sensing the open-circuit voltage of the probes.
2. Consider whether zero or infinite output resistance would be best for making the output voltage independent of the input resistance of the ADC.
3. Based on these selections of input and output resistances, use Table 1.1 on page 39 to select the amplifier type.

<table>
<thead>
<tr>
<th>Table 1.1. Characteristics of ideal amplifiers.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplifier Type</td>
</tr>
<tr>
<td>Voltage</td>
</tr>
<tr>
<td>Current</td>
</tr>
<tr>
<td>Transconductance</td>
</tr>
<tr>
<td>Transresistance</td>
</tr>
</tbody>
</table>

- **Solution**
  1. An amplifier with a high input impedance would be best for sensing the open-circuit voltage of the probes. Variations in probe impedance would have a relatively small effect.
  2. A low output impedance would be best for connecting the output to the ADC. Variations in the ADC impedance would have only a small effect on the voltage received by it.
  3. Looking at the table above, we see that a voltage amplifier would be best.

- **Design:**
  1. Given the specification that the voltage gain should be 10 ±3%, we choose a worst case error due to changes in the input impedance of ±1.5%. We choose the output impedance similarly, for a maximum error of ±1.5%.

- **Input:** the voltage divider for the input will be \( \frac{\text{R}_{\text{in}}}{R_s + \text{R}_{\text{in}}} \). We want this to vary by less than +1.5% - (-1.5%) = 3% from the highest to lowest input impedances. One way to make this happen is: \( \frac{\text{R}_{\text{in}}}{10\Omega + \text{R}_{\text{in}}} \cdot \frac{\text{R}_{\text{in}}}{10,000 + \text{R}_{\text{in}}} = 0 \), \( \text{R}_{\text{in}} \) = 1.03

  Solve \( \frac{\text{R}_{\text{in}}}{10 + \text{R}_{\text{in}}} = .03 \cdot \frac{\text{R}_{\text{in}}}{10,000 + \text{R}_{\text{in}}} = 0 \), \( \text{R}_{\text{in}} \) // Flatten

\{\text{R}_{\text{in}} \rightarrow 0.0, \text{R}_{\text{in}} \rightarrow 332.990.\}
So an input impedance of at least 333 kΩ will meet this specification.

- **Output**: the voltage divider for the output will be \( \frac{R_{load}}{R_{load} + Routput} \). We want this to vary by less than +1.5% - (-1.5%) = 3% from the highest to lowest input impedances. As before:

\[
\frac{10 000}{R_{output} + 10 000} = 1.03
\]

Solve
\[
\left[ \frac{1 000 000}{1 000 000 + Routput} - 1.03 \cdot \frac{10 000}{10 000 + Routput} \right] = 0, Routput // Flatten
\]

\{R_{output} \to 303.122\}

So an output impedance of less than 300Ω will satisfy this condition.

- **Final Design**: Choose an input impedance of 400 kΩ, and output impedance of 300Ω, and a voltage gain of 10.3 (maximum allowed by our specification).

Extreme case 1: (highest gain case) \( R_s = 10\Omega, R_{load} = 1\ M\Omega \). Then the overall source-to-output voltage gain will be

\[
Av = \frac{400 000}{400 000 + 10} \cdot 10.3 \cdot \frac{1 000 000}{1 000 000 + 300} = 10.2967
\]

Extreme case 2: (lowest gain case) \( R_s = 10 000\ , R_{load} = 100\ k\Omega \). Then the overall source-to-output voltage gain will be

\[
Av = \frac{400 000}{400 000 + 10 000} \cdot 10.3 \cdot \frac{100 000}{100 000 + 300} = 10.0187
\]

This is about twice as good as our specification, so we could be a bit more loose with our input and output impedance requirements.
Problem 1.52

Sketch the gain magnitude of a typical dc-coupled amplifier against frequency. Repeat for an ac-coupled amplifier.

- Solution:

(a) Ac-coupled amplifier

(b) Dc-coupled amplifier
Problem 1.55

The input voltage to a certain amplifier is
\[ v_i(t) = 0.1 \cos(2000\pi t + 30^\circ) \]
and the output voltage is
\[ v_o(t) = 10 \sin(2000\pi t + 15^\circ) \]
Find the complex voltage gain of the amplifier at \( f = 1 \) kHz and express the magnitude of the gain in decibels.

Solution: \[ G = \frac{10 \cdot 120^\circ}{0.1 \cdot 15^\circ} = 100 \cdot 105^\circ \]
decibels: \[ 10 \log (100) = 20 \text{ dB} \]

Problem 1.61

The input signals \( v_{i1} \) and \( v_{i2} \) illustrated in the figure below are the inputs to a differential amplifier with a gain of \( A_d = 10 \). (Assume that the common-mode gain is zero.) Sketch the output of the amplifier to scale versus time. Sketch the common-mode input signal to scale against time.

Solution: \[ V_o = A_d (v_{i1} - v_{i2}) = 10 ((v_{i1} - v_{i2}) \]. For the first millisecond the output will be 0V; from 1 ms to 2 ms, it will be -10V; from 2 ms to 3 ms it will be +10V; and after that it will be 0V.