Lecture 8
Amplifiers
(Basics)
### EE 101 Schedule

Version 10-10-11 (supersedes version of “11-5-11” -- date mistake)

<table>
<thead>
<tr>
<th>Class</th>
<th>Lecture</th>
<th>Date</th>
<th>Topic</th>
<th>Reading Ahead</th>
<th>Homework</th>
<th>Quiz</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>9-23-11</td>
<td>Introduction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>9-26-11</td>
<td>Fundamentals of Electrical Engineering</td>
<td>A &amp; S Ch 1</td>
<td></td>
<td>Pre-Req</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>9-28-11</td>
<td>Circuit Laws, Voltage &amp; Current Dividers</td>
<td>A &amp; S Ch 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>9-30-11</td>
<td>Node/Loop Analysis</td>
<td>A &amp; S Ch 3</td>
<td>Hmwk 1 Due</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>10-3-11</td>
<td>Node/Loop Analysis</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>10-5-11</td>
<td>Thévenin Equivalent Circuits</td>
<td>A &amp; S Ch 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>10-7-11</td>
<td>Norton Equivalent Circuits</td>
<td></td>
<td>Hmwk 2 Due</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>10-10-11</td>
<td>Amplifiers</td>
<td>A &amp; S Ch 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>10-12-11</td>
<td>Review for Midterm 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>10-14-11</td>
<td>Midterm 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>9</td>
<td>10-17-11</td>
<td>Op Amps</td>
<td></td>
<td>Hmwk 3 Due</td>
<td>2</td>
</tr>
<tr>
<td>12</td>
<td>10</td>
<td>10-19-11</td>
<td>Op-Amp Circuits</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>11</td>
<td>10-21-11</td>
<td>Op-Amp Circuits</td>
<td></td>
<td>Hmwk 4 Due</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>12</td>
<td>10-24-11</td>
<td>Inductance and Capacitance</td>
<td>A &amp; S Ch 6</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>13</td>
<td>10-26-11</td>
<td>First Order Transient Response</td>
<td>A &amp; S Ch 7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>14</td>
<td>10-28-11</td>
<td>RC/RL Circuits, Time Dependent Op Amp Circuits</td>
<td></td>
<td>Hmwk 5 Due</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>15</td>
<td>10-31-11</td>
<td>Second Order Transient Response</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>11-2-11</td>
<td>Review for Midterm 2</td>
<td></td>
<td>Hmwk 6 Due</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>11-4-11</td>
<td>Midterm 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>16</td>
<td>11-7-11</td>
<td>Sinusoidal Signals, Complex Numbers, Phasors</td>
<td></td>
<td>Hmwk 7 Due</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>17</td>
<td>11-9-11</td>
<td>Phasor Circuits</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>18</td>
<td>11-14-11</td>
<td>AC Power, Thévenin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>19</td>
<td>11-16-11</td>
<td>Fourier Analysis, Low Pass Filters, Decibels</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>20</td>
<td>11-18-11</td>
<td>Bode Plot, High Pass Filter, Series Resonance</td>
<td></td>
<td>Hmwk 8 Due</td>
<td>5</td>
</tr>
<tr>
<td>25</td>
<td>21</td>
<td>11-21-11</td>
<td>High Pass Filters, 2nd Order Filters, Active Filters, Resonances</td>
<td></td>
<td>Hmwk 9 Due</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>22</td>
<td>11-23-11</td>
<td>Magnetic Circuits, Materials</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>23</td>
<td>11-25-11</td>
<td>Thanksgiving Day</td>
<td></td>
<td>Hmwk 10 Due</td>
<td>6</td>
</tr>
</tbody>
</table>

12-2-11 Review for Final at normal class time and place

Final Exam Thursday, December 8th (noon to 3 pm)
Overall Goals

1. Use various amplifier models to calculate amplifier performance for given sources and loads.

2. Compute amplifier efficiency.

3. Understand the importance of input and output impedances of amplifiers.
Outline (Lecture 8)

• Basic amplifier concepts
• Cascaded amplifiers
• Power supplies and efficiency
Essence of an Amplifier

Figure 11.1 Electronic amplifier.
BASIC AMPLIFIER CONCEPTS

Ideally, an amplifier produces an output signal with identical waveshape as the input signal, but with a larger amplitude.

\[ v_o(t) = A_v v_i(t) \]
Inverting and Non-inverting Amps

(a) Input waveform

(b) Output waveform of a noninverting amplifier

(c) Output waveform of an inverting amplifier

Figure 11.2 Input waveform and corresponding output waveforms.
Inverting versus Non-inverting Amplifiers

Inverting amplifiers have negative voltage gain, and the output waveform is an inverted version of the input waveform. Non-inverting amplifiers have positive voltage gain.
The input resistance $R_i$ is the equivalent resistance we see when looking into the input terminals of the amplifier. $R_o$ is the output resistance. It causes the output voltage to decrease as the load resistance becomes smaller. $A_{voc}$ is the open circuit voltage gain.
Current Gain

Voltage-amplifier model

\[ A_i = \frac{i_o}{i_i} \]

\[ A_i = \frac{i_o}{i_i} = \frac{v_o / R_L}{v_i / R_i} = A_v \frac{R_i}{R_L} \]
Power Gain

$$G = \frac{P_o}{P_i}$$

$$G = \frac{P_o}{P_i} = \frac{V_o I_o}{V_i I_i} = A_v A_i = (A_v)^2 \frac{R_i}{R_L}$$

Upper case V and I indicate Root Mean Square (RMS) values, i.e. the effective values of a fluctuating current or voltage.
Root Mean Square (RMS) Values

\[ V(t) = V_m \cos(\omega t + \varphi) \]

The average value of \( \cos (\omega t + \varphi) \) is zero.

This is the squared version of the signal, and its mean value is \( \frac{1}{2} \).

\[
\langle P \rangle_{\text{Average}} = \frac{1}{T} \int_0^T p dt = \frac{1}{T} \int_0^T \frac{V_m^2 \cos^2(\omega t + \varphi)}{R} dt = \frac{1}{R} \left[ \frac{1}{T} \int_0^T V_m^2 \cos^2(\omega t + \varphi) \right]
\]

\[ = \frac{V_{\text{rms}}^2}{R} \]

For house power the 110 to 120 volts we are familiar with is the RMS value and the peak value is \( (110/0.707) \) or \( \sim 156 \) volts. Meters typically read RMS on the AC voltage scale unless noted otherwise.
Example

Find the voltage gain, the current gain and the power gain:

Figure 11.4 Source, amplifier, and load for Example 11.1.
Impedance Match for Max Power into Load

What load resistance maximizes the power gain?

From the Thevenin equivalent model we know that the maximum power delivered to a load is when the load resistance is equal to the Thevenin resistance of $25\,\Omega$.

\[ A_v = \frac{V_o}{V_i} = A_{voc} \frac{R_L}{R_o + R_L} = (500) \frac{25}{25 + 25} = 250 \]

\[ G = (A_v)^2 \frac{R_i}{R_L} = (250)^2 \frac{2000}{25} = 5 \times 10^6 \]
Figure 11.5 Cascade connection of two amplifiers.
Example 11.2

Find the voltage gain for each stage and for the overall cascade connection:
Simplified Models for Cascaded Amplifier Stages

First, determine the voltage gain of the first stage accounting for loading by the second stage.

The overall voltage gain is the product of the gains of the separate stages.

The input impedance is that of the first stage, and the output impedance is that of the last stage.
Input resistance and output resistance of the cascade:

\[ R_i = R_{i1} = 1 \text{M} \Omega \]
\[ R_o = R_{o2} = 100 \Omega \]
Simplified Model

$A_{voc} = 1.5 \times 10^4$  
But how do we find this?

$R_i = 1\, M\Omega$

$R_o = 100\, \Omega$
Finding the combined open circuit voltage gain $A_{voc2}$

$$A_{v1} = A_{voc1} \frac{R_{i2}}{R_{i2} + R_{o1}} = 200 \frac{1500}{1500 + 500} = 150 \text{ (same as before)}$$

$$A_{v2} = \frac{v_{o2}}{v_{i2}} = \frac{100v_{i2}}{v_{i2}} = A_{voc2} = 100 \text{ (for open output circuit)}$$

$$A_{voc} = A_{v1}A_{v2} = (150)(100) = 1.5 \times 10^4 \text{ (for combination)}$$
Figure 11.8 The power supply delivers power to the amplifier from several dc voltage sources.
The additional power comes from the power supply. The efficiency is given by:

\[ \eta = \frac{P_o}{P_s} \times 100 \]
Find the input power, output power, supply power and the power dissipated in the amplifier. Also find the efficiency of the amplifier.
Input power:

\[ P_i = \frac{V_i^2}{R_i} = \frac{(1 \times 10^{-3})^2}{100\, k\Omega} = 10^{-11}\, W \]

Output power:

\[ V_o = \frac{R_L}{R_L + R_o} 10^4 v_i = \frac{8}{8 + 2} (10) = 8V \]
\[ P_o = \frac{V^2}{R_L} = \frac{(8V)^2}{8\Omega} = 8W \]

Supply power

\[ P_s = P_A + P_B = 15W + 7.5W = 22.5W \]

\[ \eta = 100\frac{P_o}{P_s} = 100\frac{8W}{22.5W} = 35.6\% \]