Course Structure

- Lecture
- Homework – drop lowest score (NO LATE!)
- Quiz – drop lowest score (NO MAKEUPS)
- PSpice Projects (3)
- Exams (3), Final(Content from each Exam)
- Labs
  - 5 Labs/3 projects
Course Grading

Homework – 9% (low dropped)
Quizes – 7% (low dropped)
Spice – 9%
Labs – 15%
3 Exams – 60%
Class Web Page:  
http://www.ece.utah.edu/~ece2280

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What is Microelectronics?

**Definition:** The technology and techniques involved in the design, development, and construction of extremely small electronic circuits (for example, computers on a single silicon chip) (MS Encarta)

Microelectronics ~ integrated-circuit (IC) technology
(we will study what is inside an IC)
What is Microelectronics?

- Currently capable of producing circuits that contain millions of components in a piece of silicon on the order of 1cm². (S&S)

To put this in perspective, every time you make a phone call or send an e-mail message, you are using several billion transistors in worldwide communications networks (MS Encarta)
What you will learn

Understanding of signals and frequencies (Bode Plots)
What you will learn

- Characteristics of operational amplifiers
What you will learn

- Understanding of diodes, BJTs, and MOSFETs

Analysis and design using diodes, BJTs, and MOSFETs in electronic circuits
What you will learn

- Proficiency using tool to design/analyze circuits: PSPICE
Course Expectations

- 10 hours of outside study per week
- Read book
- Understand examples
- Rewrite procedural steps
- Practice!!!
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Class Load
- Very busy throughout semester.
- Surveys show **AT LEAST 10 HOURS** of outside studying needed (sometimes 20 hrs)
- Organize your time
- Understand the material through Practice
- Make permanent notes for procedural steps

**REVIEW:**

*Example A*

Derive an expression for $v_i$. The expression must not contain more than the circuit parameters $v_i, i_1, R_1, R_2, R_3,$ and $R_4$. *(Hint: It is not just a simple voltage divider)*

\[
\begin{align*}
V_1 &= i_1 R_1, \\
KCL: \quad \text{Summation of currents} & \quad i_a - i_1 - i_3 = 0 \quad \text{(1)} \\
KVL: \quad \text{Voltage loop} & \quad + i_1 (R_2) + i_3 (R_3) - V_a = 0 \quad \text{(2)}
\end{align*}
\]

From (1) \( \Rightarrow \quad i_3 = i_a - i_1 \) (plugging this into (2))

\[
\begin{align*}
&\quad i_1 (R_1 + R_2) - (i_a - i_1)(R_3) - V_a = 0 \\
&\quad i_1 (R_1 + R_2 + R_3) = i_a R_3 + V_a \\
&\quad \therefore \quad i_1 = \frac{i_a R_3 + V_a}{R_1 + R_2 + R_3} \\
&\quad V_1 = i_1 R_1 = \frac{i_a R_3 R_1 + V_a R_1}{R_1 + R_2 + R_3}
\end{align*}
\]

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Example B
Derive an expression for $I_1$. The expression must not contain more than the circuit parameters $\alpha, V_0, R_1$ and $R_2$. (Make sure that to eliminate $V_2$ from the answer) ($\alpha \neq 1$).
THEVINEN EQUIVALENCE:

CASE 1: Thevenin Equivalent (circuit with only independent sources)
Step 1. Turn off all independent sources. (This means V=0 (short) and I=0 (open))
Step 2. Rth=equivalent R seen between the two desired nodes a-b.
Step 3. Vth=open circuit voltage between a-b.

CASE 2: Thevenin Equivalent (circuit with dependent sources)
Step 1. Calculate the open circuit voltage, Vth.
Step 2. Calculate Rth.
   (a) Remove all independent sources.
   (b) Apply a voltage source Vtest between a-b and determine the resulting current Itest. OR apply a current source Itest between a-b and determine the resulting voltage Vtest. Using 1V or 1A as the value of the applied test sources allow easy multiplication or division.
   (c) Rth=Vtest/Itest

Example. Case 1: (independent sources) Find Thevenin across R2 (Removing R2 from the circuit).

Step 1. Turn off all independent sources. (This means V=0 (short) and I=0 (open))
and find equivalent R.

Example Case 2:
Find Thevenin between a-b.

Step 1: (Find Vo(open circuit voltage))
Vo=-5I2(10||40)=-5i2(10)(40)/50 = -40i2
i2=-3v1(10)/60 = -1/2v1
Vg-10i1-v1-3v1(3)=0 (i1=0) => 10v1=Vg
Vo=-40(-1/2)(Vg/10) = +2Vg=Vth
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Step 2:
Find Rth: TEST SOURCE
(a) Remove all independent sources.
(b) Apply a test source (Itest in this case). Analyze circuit for Vtest=Vo in this case.

\[ V_0 = V_{test} = (10||40)*(I_{test}-5i2) \]
\[ i_1 = 0 \]
\[ v_1 = -3v_1(3) \Rightarrow v_1 + 9v_1 = 0 \Rightarrow v_1(10) = 0 \Rightarrow v_1 = 0 \]
\[ i_2 = 0 \]
\[ V_{test} = 8I_{test} \]
\[ R_{th} = 8I_{test}/I_{test} = 8\text{ohm} \]

Example New Symbol

Solve for I, I1, I2, and V1:
\[ I = \frac{12V}{2k + 3k/6k} = \frac{12}{2k + (3k/6k)} = \frac{12}{2k + 2k} = 3mA \]
\[ I_1 = \frac{V_1}{5k}, I_2 = \frac{V_1}{6k} \]
\[ I = I_1 + I_2 = V_1 \left( \frac{1}{5k} + \frac{1}{6k} \right) = V_1 \left( \frac{3k}{6k} \right) = V_1 \left( \frac{1}{2k} \right) \Rightarrow V_1 = I \cdot 2k = 3m(2k) = 6V \]
\[ I_1 = \frac{6}{3k} = 2mA; I_2 = \frac{6}{6k} = 1mA \]

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Signals
A DC (direct current) signal refers to a fixed voltage whose polarity never reverses. {Ex. 5V, -15V}

An AC (alternating current) occurs when charge carriers periodically reverse their direction of movement. {Ex. Sinusoid => 5sin(10t), Square Waves, Sawtooth-shaped}

- The voltage of an AC power source changes from instant to instant in time.
- Wall plug is AC with a frequency of 60 hertz and 120V
  - 120\*1.414 peak value
- RMS value = peak value/\sqrt{2}

Real signals such as your voice, environmental sensors, etc. are time-varying voltages or currents that carry information.

- Transducers transform one form of energy into another:
  - Ex: Microphone, Camera, Thermistor or other thermal sensor, Potentiometer, Light sensor, Computer, etc.
- Sine waves are "pretend" signals
  - Although sine waves are not real signals, we use them to simulate signals all the time, both in calculations and in the lab. This makes sense because all signals can be thought of as being made up of a spectrum of sine waves.

These types of signals can be hard to characterize mathematically. If a signal is periodic but arbitrary in amplitude, recall that it can be expressed by the Fourier series (a series of sinewaves of different frequencies and amplitudes).

Examples
Sketch the following waveforms. Identify the dc component of the waveform and the ac component of the waveform.

a. $V_s=5\sin(10t)$ V

b. $V_s=2V+4\sin(5t+90^\circ)$ V

c. $V_s=1V \pm 1V$

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Sine wave:
Time domain:

\[ v(t) \]

\[ t \text{ (ms)} \]

amplitude := 10 V

\[ V_{\text{RMS}} := \frac{10 \text{ V}}{\sqrt{2}} \]

\[ f := 200 \text{ Hz} \]

\[ T := 5 \text{ ms} \]

\[ f := \frac{1}{T} \]

\[ \omega := 2\pi \cdot f \]

Frequency domain:

Example
When analyzing a time dependent element (capacitors), translate into frequency domain =>

\[ C = \frac{1}{jwC} = \frac{1}{sc} \]

and then analyze the circuit using normal circuit analysis techniques. Analyze the circuit to the right to find the transfer function \( \frac{V_o}{V_i} \). Solve the circuit symbolically first (with \( R_1, R_2, R_3, C \)) and then plug in their values.

Get \( V_{th} \) and \( R_{th} \):

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What does this equation mean? By substituting $s = j\omega$ in the above equation. The magnitude of the equation is:

$$\frac{133n(\omega)}{266.7n(\omega)(j+1)} = \frac{|133n(\omega)|}{|266.7n(\omega)(j+1)|} = \frac{133n(\omega)}{\sqrt{(266.7n(\omega))^2 + 1^2}}$$

This magnitude can now be graphed with the x-axis as $\omega$ and the y-axis as the calculated value. This is one of the graphs used for the Bode plots. To plot this, an understanding of dB is needed.

**Decibels**

Your ears respond to sound logarithmically, both in frequency and in intensity. Musical octaves are in ratios of two. "A" in the middle octave is 220 Hz, in the next, 440 Hz, then 880 Hz, etc... It takes about ten times as much power for you to sense one sound as twice as loud as another.

10x power, = 2x loudness

A bel is such a 10x ratio of power. Power ratio expressed in bels = $\log\left(\frac{P_2}{P_1}\right)$ bels

The bel is named for Alexander Graham Bell.

It is a logarithmic expression of a unitless ratio (like gain).

The bel unit is never actually used, instead we use the decibel (dB, 1/10th of a bel).

Power ratio expressed in dB = $10 \log\left(\frac{P_2}{P_1}\right)$ dB

dB are also used to express voltage and current ratios, which related to power when squared. $P = \frac{V^2}{R}$ = $I^2R$

Voltage ratio expressed in dB = $20 \log\left(\frac{V_2}{V_1}\right)$ dB

Current ratio expressed in dB = $20 \log\left(\frac{I_2}{I_1}\right)$ dB

These are the most common formulas used for dB

Some common ratios expressed as dB

- $20 \log\left(\frac{1}{\sqrt{2}}\right) = -3.01$ dB
- $\frac{3}{10} = 0.308$ dB
- $20 \log\left(\frac{\sqrt{3}}{3}\right) = 3.01$ dB
- $\frac{3}{20} = 0.17$ dB
- $20 \log\left(\frac{2}{3}\right) = 6.021$ dB
- $\frac{5}{20} = 0.25$ dB
- $20 \log\left(\frac{\sqrt{2}}{1}\right) = 3.01$ dB
- $\frac{1}{100} = 0.01$ dB
- $20 \log\left(\frac{100}{1}\right) = 40$ dB
- $\frac{40}{20} = 2.00$ dB

We will use dB fairly commonly in this class, especially when talking about frequency response curves.

**Example Bode**

The frequency domain expression for the output over the input of a circuit is solved to be

$$\frac{\text{output}}{\text{input}} = \frac{10^5(s+5)}{(s+1)(s+5000)}$$

Substitute $s = j\omega$ into the above equation and calculate the magnitude (dB) and phase (degrees). Plug in values for $\omega$ equal to $10^4$, $0.8$, $0.9$, $10^0$, $2$, $3$, $4$, $5$, $6$, $7$, $10^1$, $10^2$, $10^3$, $3000$, $4000$, $5000$, $6000$, $7000$, $10^4$, $10^5$ rad/sec and plot these values on a semilog graph for both magnitude and phase. Recall that magnitude, $|a + bj| = \sqrt{a^2 + b^2}$ and the phase,

$$\angle(a + bj) = \tan^{-1}\left(\frac{b}{a}\right)$$

**Magnitude:**

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Bode Plots
- 2 plots – both have logarithm of frequency on x-axis
  - y-axis magnitude of transfer function, \( H(s) \), in dB
  - y-axis phase angle, in degrees

The plot can be used to interpret how the input affects the output in both magnitude and phase over frequency. To sketch the graphs, the circuit is first analyzed to find output/input (transfer function). This equation is used as the basis for the plots. The equation is analyzed for magnitude and phase as shown in the previous example.

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**Frequency response**

The “response” of a system or circuit is the output for a given input.

A “transfer function” is a mathematical description of how the output is related to the input.

\[
\text{output} = \text{Transfer function} \times \text{input}
\]

or...

\[
\text{Transfer function} = \frac{\text{output}}{\text{input}}
\]

No real system or circuit treats all frequencies the same, so all real transfer functions are functions of frequency.

\[
\text{Transfer function} = H(\omega) \text{ or } H(f) \text{ or, } \text{Transfer function} = H(s)
\]

The transfer function can be used to describe the “frequency response” of a circuit. That is, how does the circuit respond to inputs of different frequencies.

**Summary**

1. Be able to analyze a circuit with independent and dependent sources to find all currents and voltages within the circuit.
2. Find the Thevenin Circuit for circuits containing independent and dependent sources.
3. Understand signals: peak value, RMS value, peak to peak value, frequency, AC vs DC, describe waveforms mathematically.
4. Analyze circuits containing capacitors to obtain the transfer function.
5. Convert between dB and V/V.
6. Apply complex math to a transfer function and plot the Bode plots.

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