Welcome to EECS 16A!
Designing Information Devices and Systems I

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Module 2
Lecture 1
Introduction to Circuit Analysis
(Note 11)
Designing Information Devices and Systems
Module 2 – More tools to build systems

- Analog World
- Sensor
- Processing
- Actuation
Module 2 – More tools to build systems

Analog World | Sensor | Processing | Actuation
Module 2 – More tools to build systems

Analog World

Sensor

Processing

Actuation
Module 2 – More tools to build systems

Analog World

Sensor

Processing

Actuation 16B
System Example - Electromyography

☑ Monitors muscle activity
☑ Used in gesture recognition
☑ Impact in rehabilitation

☒ Bulky electrodes
☒ Poor accuracy – low resolution
☒ Computation performed on external devices
System Example - Electromyography
In Module 2 we will learn how to analyze circuits.

We need to be able to go from a real-world circuit, to a circuit model, and vice versa.
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We need to be able to go from a real-world circuit, to a circuit model, and vice versa.

Then we need to know how to solve the model...

Note: the tool used by computers to analyze circuits is *linear algebra*!
Electrical Circuit Analysis Algorithm (tool)

SPICE (Simulation Program with Integrated Circuit Emphasis): started as a student project at Berkeley!

Now the basis for open-source electronic circuit simulation, to design and model device characteristics and check circuit boards.
Electrical Circuit Analysis Algorithm (tool)
Definitions needed to analyze a circuit: quantities

<table>
<thead>
<tr>
<th>Quantities</th>
<th>Analytical Symbol</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>I</td>
<td>Amperes [A]</td>
</tr>
<tr>
<td>Voltage</td>
<td>V</td>
<td>Volts [V]</td>
</tr>
<tr>
<td>Resistance</td>
<td>R</td>
<td>Ohms [Ω]</td>
</tr>
</tbody>
</table>

I ⇒ flows through an element  
V ⇒ applied across an element  
R ⇒ opposition to current flow
Definitions needed to analyze a circuit: Circuit Diagram

Collection of elements, where each element has some voltage across it and some current through it
Key circuit elements: Wire

\[ V_{	ext{elem}} = 0 \]
\[ I_{	ext{elem}} = ? \]

(set by the external circuit)
Key circuit elements: Resistor

\[ V_{\text{elem}} = R \cdot I_{\text{elem}} \]

(Ohm's law)
Key circuit elements: Open circuit

$I_{elem} = 0$

$V_{elem} = ?$

(set by external circuit)
Key circuit elements: Voltage Source

\[ V_{elem} = V_s \]

\[ I_{elem} = ? \]

(set by external circuit)
Key circuit elements: Current Source

\[ I_{\text{elem}} = I_s \]

\[ V_{\text{elem}} = ? \]

(set by ext. circuit)

Velement and Ielement can be positive or negative
Rules for circuit analysis: Kirchoff’s Voltage Law (KVL)

Sum of Voltages across the elements in a loop equal zero
Rules for circuit analysis: Kirchoff’s Current Law (KCL)

The current flowing into any junction must equal the current flowing out.

\[ I_{c13} + I_{c12} = 0 \]

\[ I_{c14} = I_{c12} \]
\[ I_{c12} = I_{c13} \]
\[ I_{c13} = I_{c14} \]
\[ I_{c14} = I_{c11} \]

Example 2:
\[ I_{c15} + I_{c16} = I_{c14} \]
Rules for circuit analysis: KCL within the element

The current flowing into any junction must equal the current flowing out
Rules for circuit analysis: KCL within the element

The current flowing into any junction must equal the current flowing out.

Both allowed!

Passive sign convention
Circuit Analysis Algorithm

Voltage = difference of two potential

Find: currents through elements and potentials of inputs/outputs of each element (junctions)

\[ V_1 + V_i - U_2 \]

\[ U_1, U_2 \ldots U_4 \rightarrow \text{potentials} \]

\[ V_i = U_1 - U_2 \text{ (Voltage)} \]

\[ I_i - \text{current} \]

Elem 1 \( \rightarrow \) WIRE \( \Rightarrow \) \( V_1 = 0 \)

\[ U_1 = U_2 \]

Collapse junctions with same potential into a node.
Circuit Analysis Algorithm : step 1

Pick a reference node and label it as 0 potential. All voltages measured relative to this node.

\begin{center}
\includegraphics[width=0.5\textwidth]{circuit_diagram}
\end{center}

tells you where the reference is.
Circuit Analysis Algorithm : step 2

Label all remaining nodes as potentials $U_i$

$[U_1 \ldots U_{N-1}]$

$U_i - 0 = U_i = V$

Voltage between node 1 and node 0
Circuit Analysis Algorithm: step 3

Label all branch currents with $I_m$
 Arbitrarily pick directions of $I_m$
 $[I_1 \ldots I_k]$
Circuit Analysis Algorithm : step 4

Add signs + and – element voltages to each element following the passive sign convention
Circuit Analysis Algorithm: step 5

Formulate A

\[ \mathbf{x}' = \mathbf{b} \]

\[ \mathbf{X} = \begin{bmatrix} H_1 & \cdots & H_N \\ \vdots & \ddots & \vdots \\ H_1 & \cdots & H_N \end{bmatrix} \]

vector of unknowns
Circuit Analysis Algorithm: step 6

Use KCL to fill as many rows of A as possible (linear independence) # Nodes - 1 = N - 1

\[ I_1 = I_2 \]
\[ I_1 - I_2 = 0 \]

\[
\begin{bmatrix}
1 & -1 & 0 \\
\end{bmatrix}
\begin{bmatrix}
I_1 \\
I_2 \\
V_i
\end{bmatrix}
= 
\begin{bmatrix}
0
\end{bmatrix}
\]
Circuit Analysis Algorithm: step 7

Use current-voltage relationships for each element to fill the rest of the A matrix.

**Voltage element:**
- $V_{el_1} = -V_s$
- $V_{el_1} = 0 - U_1 = -U_1$
- $U_1 = V_1$✓

**Resistor:**
- $V_{el_2} = I_2 \cdot R$
- $V_{el_2} = U_1 - O = U_1$
- $U_1 = I_2 \cdot R$
- $I_2 \cdot R - U_1 = 0$ ✓

\[
\begin{bmatrix}
1 & -1 & 0 \\
0 & 0 & 1 \\
0 & R & -1
\end{bmatrix}
\begin{bmatrix}
I_1 \\
I_2 \\
U_1
\end{bmatrix} =
\begin{bmatrix}
0 \\
V_5 \\
0
\end{bmatrix}
\]