Lecture 1

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- Broad circuit categories:
  - Information processing $\rightarrow$ cell phone, GPS, cable TV
  - Power delivery $\rightarrow$ AC-to-DC power adapter, power amplifiers, EVs
- Applications
  - Communication systems
  - Medical electronics
  - Computers (digital signal processing)
  - Instrumentation
  - Control systems
  - Power systems
  - Toys
- Electronic circuits that are manufactured as integrated circuits (ICs)
  - "Chips" — created with semiconductor device fabrication processes
- Semiconductor Industry
  - 1947
    * First transistor was invented at Bell Laboratories by William Shockley, John Bardeem, and Walter Brattain
    * "The basis of modern electronics"
  - 1958 — 1961
    * Introduction of the integrated circuit by Jack Kilby (Texas Instruments) and Robert Noyce (Fairchild Semiconductor)
    * Enabled miniaturization and mass production of chips

- Today
  - Smallest dimensions of features in the silicon around 5 [nm]
  - Up to >2.5 billion transistors per chip
  - >$300 billion global revenue

- Course Overview
  - Amplifier concepts
  - Study of electronic devices
    - Operational amplifiers (Op-Amps)
    - Diodes
    - Bipolar junction transistors (BJTs)
    - Metal-oxide-semiconductor field effect transistors (MOSFETs)
  - Design and analysis of electronic circuits
    - Analog amplifiers, rectifier circuits
    - Digital logic

- Main Course Goals
  - Understand the operation of fundamental electronic devices (op-amps, diodes, BJTs, MOSFETs)
  - Analyze and design operational amplifier circuits and rectifier circuits
  - Analyze and design amplifiers with BJTs and MOSFETs
  - Be able to identify CMOS logic circuits (NOT, NAND, NOR), and analyze voltage transfer curves and propagation delays
  - Simulate electronic circuits using PSPICE

- Review — Some Circuit Analysis Highlights
  - Element combination rules (parallel, serial)
  - Ohm's Law: $I = V/R$
  - KVL for a circuit loop $\rightarrow \sum_j v_j = 0$
  - KCL at a node $\rightarrow \sum_j i_j = 0$
  - Superposition principle
    - If input A produces response X and input B produces response Y, then input (A+B) produces response (X+Y)
    - Holds only for linear circuits
    - Very useful for circuits with multiple voltage and current sources
  - Thévenin and Norton form of signal sources

    * Valid only in linear circuits

- Element Combination Rules
  - Resistors in series can be summed ($R_1 + R_2 + \cdots + R_n = R_t$)
  - Resistors in parallel can be summed via conductances $\left(G_x = \frac{1}{R_x}\right)$ can be combined to get $\rightarrow G_1 + G_2 + \cdots + G_n = G_t$
  - Voltages in series can be summed ($V_1 + V_2 + \cdots + V_n = V_t$)
  - Voltages in parallel will not occur, as it is illogical to place them in such a manner (and is the same reason current sources in series do not occur)
  - Current sources in parallel may be summed ($i_1 + i_2 + \cdots + i_n = i_t$)
- Analysis of Large Circuits
  - Write all expressions for the circuit
    * At elements (Ohm's Law)
    * At nodes (KCL)
    * For loops (KVL)
  - Eliminate redundant equations (keep only independent equations)
  - Solve the system of equations for the unknown variables
- Thévenin and Norton Equivalent Representations
  - Thévenin to Norton transformation
    * Set $I_s = V_s/R_s$ (short-circuit current), and $R_P = R_s$
  - Norton to Thévenin transformation
    * Set $V_s = I_s R_s$ (open-circuit voltage), and $R_s = R_P$
  - In more complex cases, R_s and R_P are the equivalent resistances seen at terminals
- A circuit can be broken into "source" components by assuming an open circuit for current sources, and short circuit for voltage sources
- This gives us components which we can then sum up via the superposition principle:

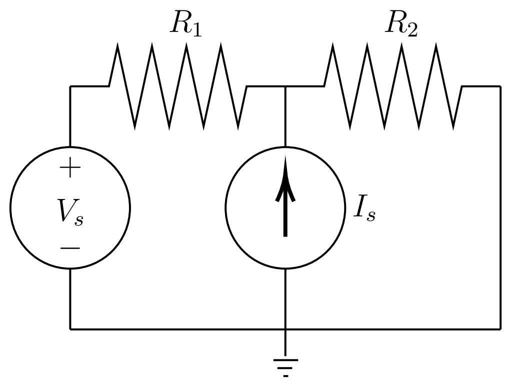

Figure 1: Initial Circuit

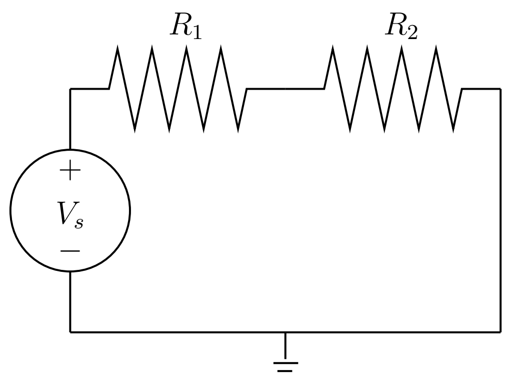

Figure 2: Voltage Component

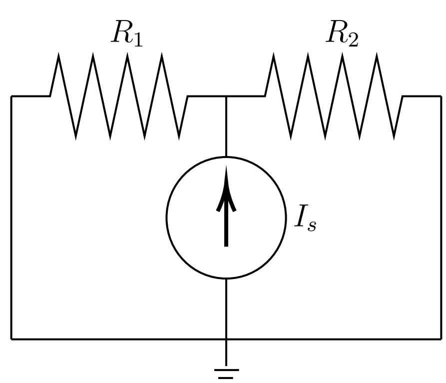

Figure 3: Current Component

- Amplification
  - Voltage gain: $|A_v|$
    - When $|A_v|$ is constant: linear amplifier
    - When $|A_v|$ is not constant: non-linear amplifier
  - Non-inverting amplifier: $v_o(t) = A_v v_i(t)$
  - Inverting amplifier: $v_o(t) = -A_v v_i(t)$
- Voltage-Amplifier Model

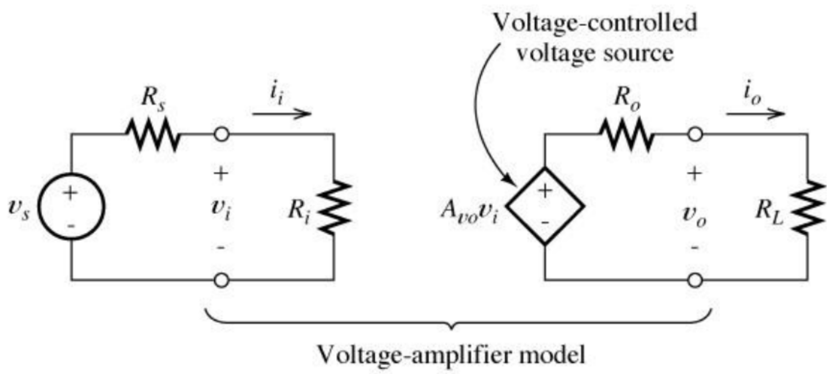

Figure 4: Reference Figure for the Voltage-Amplifier Model

  - Parameters
    - v_s is the input voltage source, which has a series resistance R_s
    - R_i and R_o are the input and output resistances, respectively
    - A_{vo} is the open-circuit voltage gain
    - R_L is the load resistance
  - Remember: This is a simplified representation of an amplifier
  - Current gain: $A_i = \dfrac{i_o}{i_i} = \dfrac{(v_o/R_L)}{(v_i/R_i)} = A_v(R_i/R_L)$
  - Loaded voltage gain: $A_v = \dfrac{v_o}{v_i} \neq A_{vo}$
  - Power gain: $G = \dfrac{P_o}{P_i} = \dfrac{V_o I_o}{\underbrace{V_i I_i}_{\text{RMS}}} = A_v A_i = A_v^2 \cdot \dfrac{R_i}{R_L}$
  - For optimum voltage transfer, $R_L >> R_o$
- Loading Effects
  - Refer to the same figure (Figure 4) as for the Voltage-Amplifier Mode

- Input signal attentuation: $v_i = v_s \left(\dfrac{R_i}{R_i + R_s} \right)$
- Output signal attentuation: $v_o = A_{vo} v_i \left(\dfrac{R_L}{R_L + R_o} \right)$
- Loaded voltage gain of the amplifier: $A_v = \dfrac{v_o}{v_i} = A_{vo} \left(\dfrac{R_L}{R_L + R_o} \right)$
- Voltage gain from source to load $A_{vs} = \frac{v_o}{v_s} = A_{vo} \left(\dfrac{R_i}{R_i + R_s} \right) \left(\dfrac{R_L}{R_L + R_o} \right)$

- Decibel Notation
  - Use $20 \log(X)$ for voltages and currents
    - $A_{v\mathrm{dB}} = 20 \log(|A_v|)$
    - $A_{i\mathrm{dB}} = 20 \log(|A_i|)$
  - Use $10 \log(X)$ for powers
    - $G_{\mathrm{dB}} = 10 \log(|G|)$
  - Quantities in decibels are added when two or more amplifiers are connected in series (called "cascaded")