Fundamentals of Electronics
Week 6

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Agenda: Review

- Topics We've Covered and Things to Remember
- Examples

Week 1 Agenda

- Introductions
- Administrivia: Website, Syllabus, Course Components
- Electronic Components
- Review of Circuits

Circuits Review

- Sources, Resistors, Capacitors, Inductors
- Kirchoff's Current and Voltage Laws (KCL, KVL)
- Analysis and Design Problems
  - Node and Mesh Analysis
  - Series and Parallel
  - Current and Voltage Dividers
  - Superposition
  - Thévenin and Norton Equivalent Circuits
  - DC, Transients, Sinusoids

Week 2 Agenda

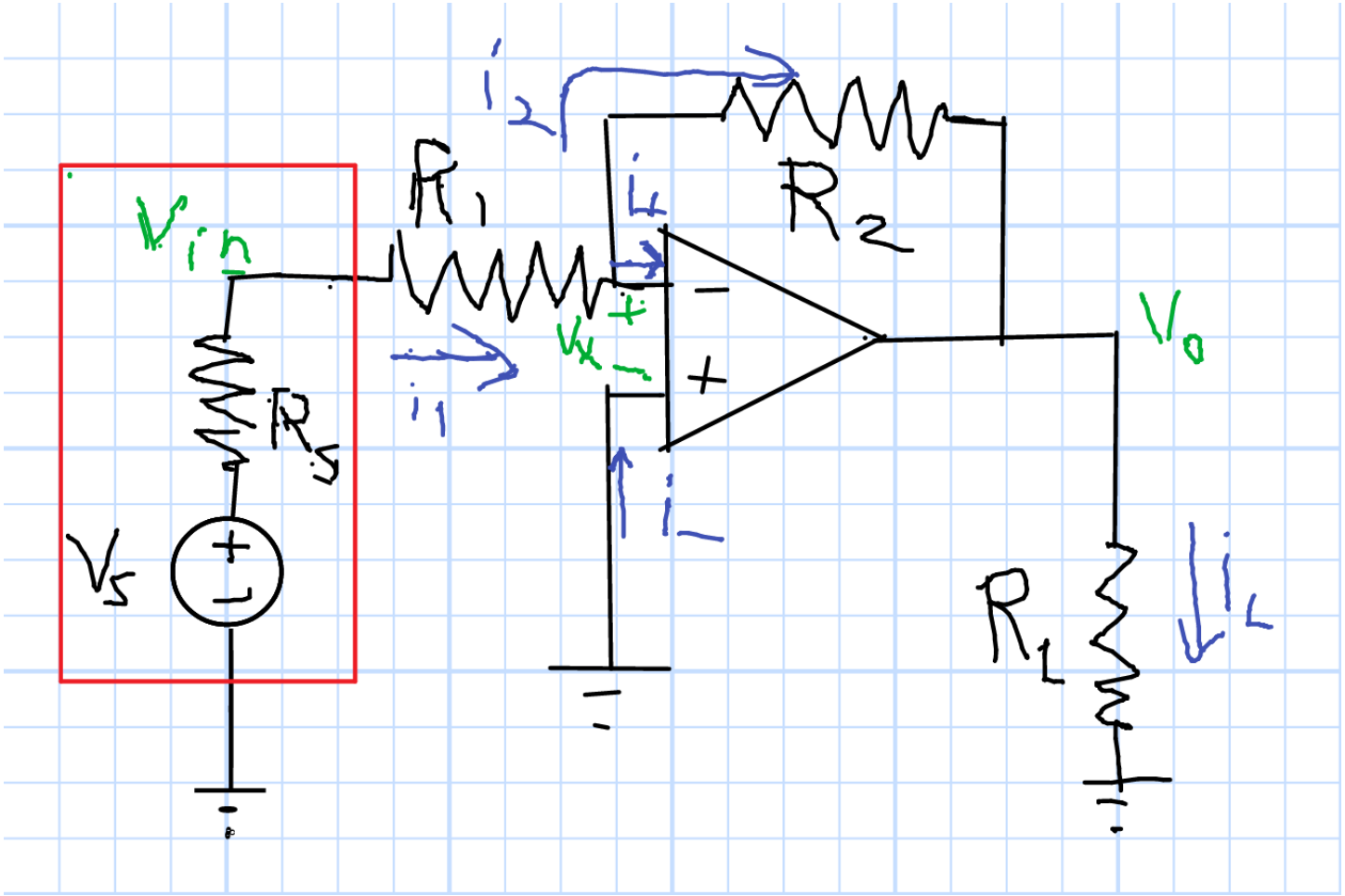
- Amplifier Models
- Ideal Operational Amplifier
- Example Circuits

Ideal Op–Amp

- Rules
  - Input Currents Zero
  - Input Differential Voltage Zero
- Exceptions
- Compute Gain (including dB), Input/Output Impedances, Bandwidth

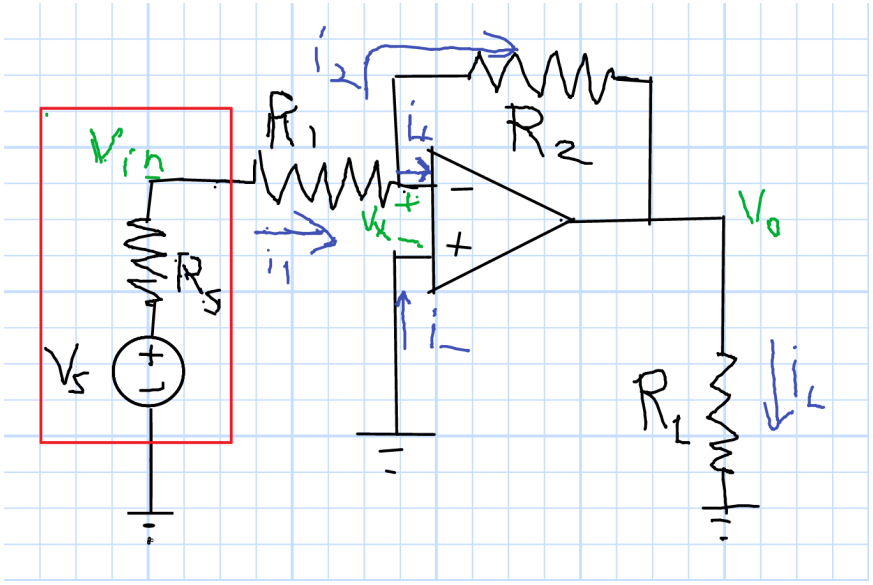
Inverting Amplifier Circuit

$I_+ = 0,\ I_- = 0,\ v_x = 0$: Virtual Ground



$i_1 = i_2$ so $v_0 = -v_{in}\frac{R_2}{R_1}$ or $A_v = -\frac{R_2}{R_1}$

Impedances



- Virtual Ground

$$v_+ = v_-$$

- Input Impedance

$$R_{in} = R_1$$

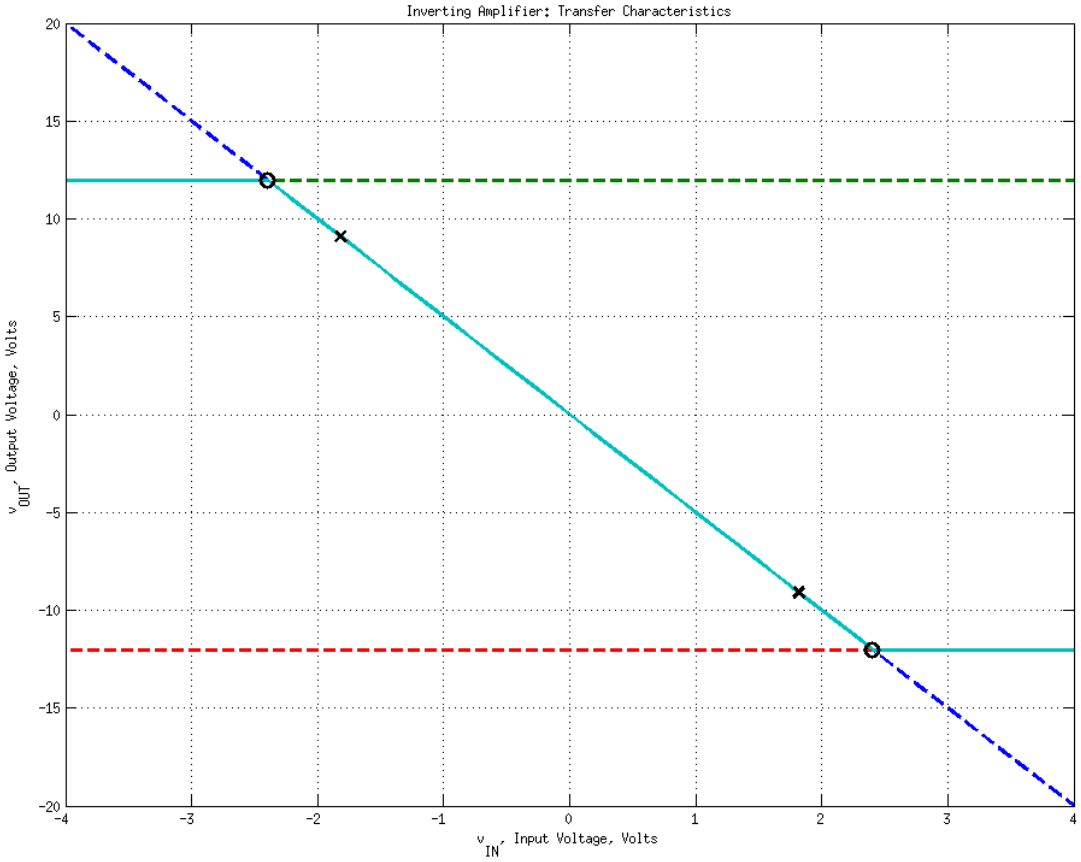
- Output Voltage $= A_v v_{in}$ regardless of load

$$R_{out} = 0$$

Week 3 Agenda: Operational Amplifiers

- Linear Effects
  - Input and Output Impedances
  - **Finite Gain,** A_{OL}
  - **Gain–Bandwidth Product**
- Nonlinear Effects
  - **Voltage Limit**
  - Current Limit
  - Slew Rate
- DC Imperfections (Know what they are)
  - Bias and Offset Currents
  - Offset Voltage
- Differential Amplifiers

Voltage Limits Example



±12–Volt Power Rails. Blue dash is ideal. Cyan solid is actual.

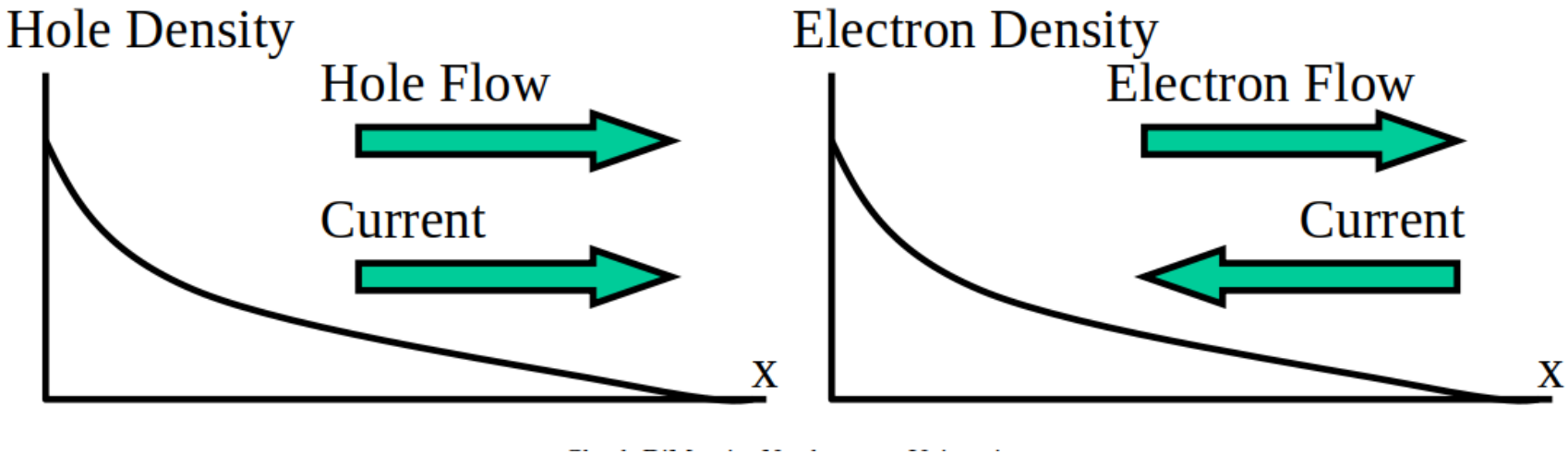
Week 4 Agenda

- Basic Physics in Intrinsic Silicon
  - Semiconductors
  - **Diffusion Current: Know the Equations**
  - **Drift Current: Know the Equations**
- Semiconductor Doping
- Junction
  - Open–Circuit
  - Reverse Bias and Breakdown
  - Forward Bias
- Photodiodes

Diffusion Currents

$$J_p = -qD_p \frac{dp}{dx} \qquad J_p \approx -1.6\times10^{-19}\,\text{Coul}\times 12\,\frac{\text{cm}^2}{\text{sec}}\times\frac{dp}{dx}$$

$$J_n = qD_n \frac{dn}{dx} \qquad J_n \approx -1.6\times10^{-19}\,\text{Coul}\times 34\,\frac{\text{cm}^2}{\text{sec}}\times\frac{dn}{dx}$$



Drift Current

Hole Velocity

$$v = \mu_p E$$

Electron Velocity

$$v = -\mu_n E$$

$$J_{drift} = q(p\mu_p + n\mu_n)E$$

$$J_{drift} = \sigma E$$

Conductivity

Note: Resistance is $R = \ell / (\sigma A)$

Drift

Velocity $v \propto E$

Hole Velocity

$v = \mu_p E$

- v: Velocity (cm/s)
- μ: Mobility
- E: Field (V/m)

$$v \approx 480 \frac{\text{cm}^2}{\text{Vs}} E$$

Electron Velocity

$$v = -\mu_n E$$

$$v \approx -1350 \frac{\text{cm}^2}{\text{Vs}} E$$

Velocities are Average
Collisions are Important

Current Summary

Diffusion

$$J_{diffusion} = -q\left(D_p \frac{dp}{dx} + D_n \frac{dn}{dx}\right)$$

Drift

$$J_{drift} = q(p\mu_p + n\mu_n)E$$

Relationship

$$\frac{D_p}{\mu_p} = \frac{D_n}{\mu_n} = V_T$$

$$J = q\left(\mu_p\left(pE + V_T \frac{dp}{dx}\right) + \mu_n\left(nE + V_T \frac{dn}{dx}\right)\right)$$

Doping

- N_D, N_A
- $np = n_i^2$

Diodes

- Shockley Equation
- Breakdown and Zener Diodes

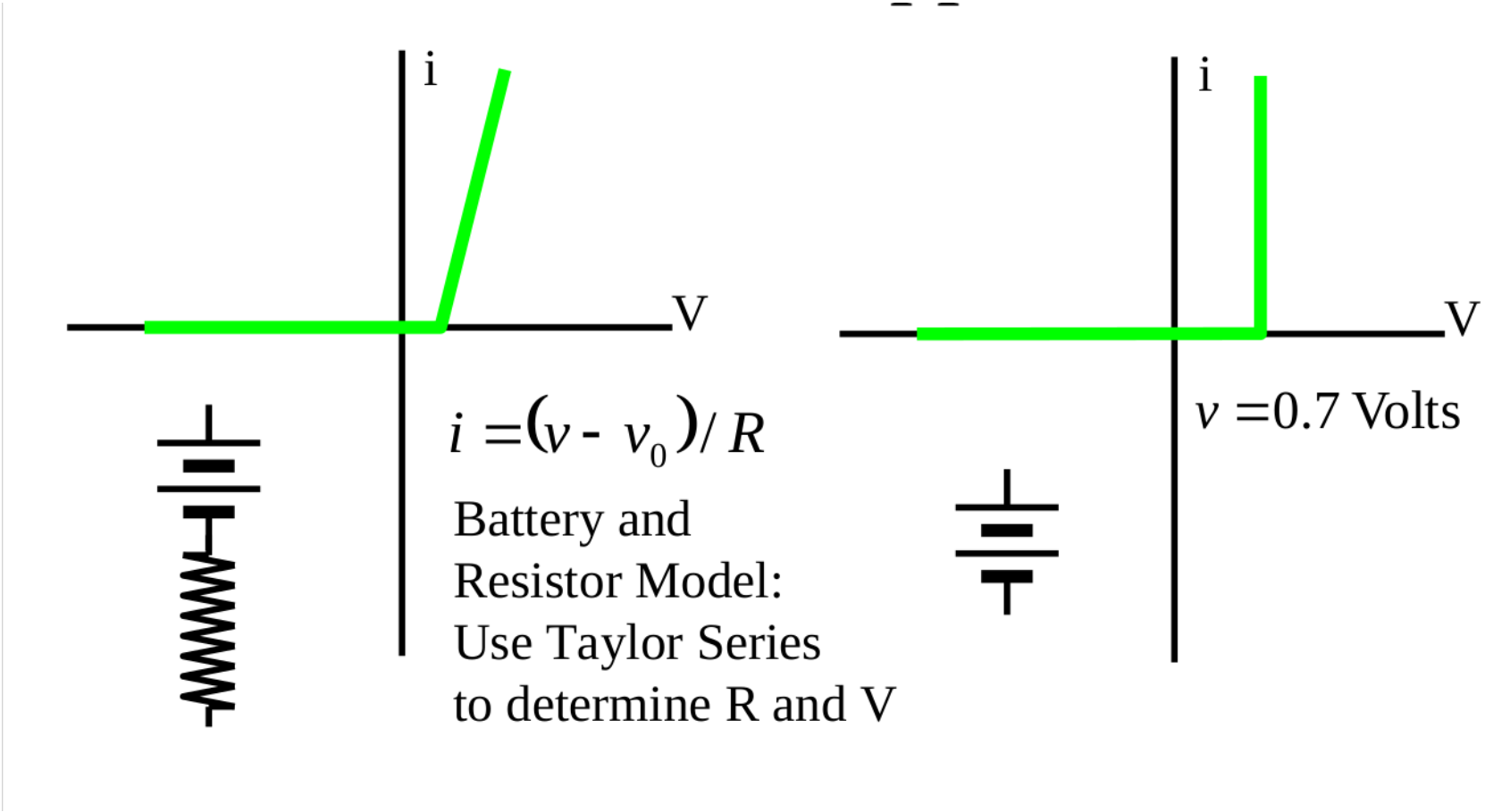
Week 5 Agenda

- Solving the Transcendental Equation
  - Iterative Methods
  - Piecewise Linear Approximation
  - Taylor Series
- Examples
  - Regulators
  - AC to DC Power Supplies
    Rectification, Filtering, Regulation
  - Full–Wave Rectifier
  - Limiters
  - Diode Logic
  - Photodiode Circuits

Piecewise Linear Models

- Ideal Diode
- 0.7 Volt Model

Two More Piecewise Linear Approximations



More Complicated Forward Segments

DC and AC Models

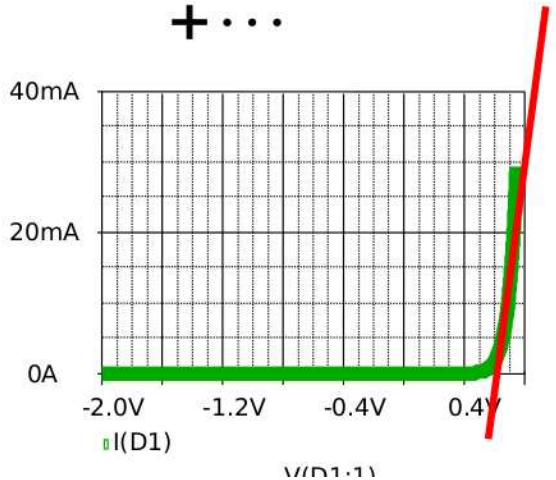
$$i(v) = I_s\left(e^{v_0/V_T} - 1\right) \longrightarrow i_D = I_D^{(DC)}$$

$$+\frac{I_s}{V_T}e^{v_0/V_T}\left(v - v_0\right) \longrightarrow +\frac{I_s}{V_T}e^{V_D^{(DC)}/V_T}v_d^{(AC)}$$

$$+I_s\left(\frac{e^{v_0/V_T}}{V_T}\right)^2\left(v - v_0\right)^2$$

$$+\cdots$$

$$+\cdots$$



Model Approximation

- DC Model Approximation

$$I_D^{(DC)} = I_s\left(e^{V_D^{(DC)}/V_T} - 1\right) \qquad I_D^{(DC)} \approx I_s e^{V_D^{(DC)}/V_T}$$

- AC Model Approximation

$$id_D^{(AC)} + \frac{I_s}{V_T} e^{V_D^{(DC)}/V_T} v_d^{(AC)} \qquad i_d^{(AC)} + \frac{I_D^{(DC)}}{V_T} v_d^{(AC)}$$

- Equivalent Resistor

$$R_{eq} \approx \frac{V_T}{I_D^{(DC)}} \approx \frac{25\text{mV}}{\text{few mA}}$$