CSE251: Electronic Devices and Circuits

Lecture 0

Introduction to Electronic Devices

Prepared By:

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Outline

- Logistical information
  - Instructor Information
  - Administrative Details
  - Marks Distribution
  - How to get an A/A+ in CSE251?
  - How to ~~get an A/A+~~ **pass** in CSE251?
  - Course Outline
  - Course Outcome (**CO**s)
- Introduction
  - Abstraction Levels
  - Historical Perspective
  - Vacuum Tubes
  - Computer Systems with BJTs (60s)
  - Computer Systems with MOSFET (60s)
  - Moore’s Law
  - Some Future Outlook

Instructor information

- Shadman Shahid [HAD]
- Seat No. – 4N159:
  - Consultation: **SUNDAY – 11 AM to 2 PM**
- Reachable via mail or discord:
  - Mail: ext.shadman.shahid@bracu.ac.bd
  - Discord: shadman<dot>shahid
- Research Interest:
  - Photonics in computational devices

Administrative Details

- Course Discord: Will be updated soon.
- Course Drive folder: CSE251-Spring24-HAD
  - Course Handout – Syllabus, Grading Policy.
  - Course Calendar
  - Homework Assignments
  - Past Exams and Practice Problems
  - Class Notes
  - Recorded Lectures

Marks Distribution

Assessment	Percentage	Total number of assessments	Number of assessment to be graded
Attendance	8%	-	-
Assignment	12%	5	Best N-1
Quiz	15%*	4*	Best N-1
Midterm	20%	1	1
Final	20%	1	1
Lab	25%	-	-

*I will take pop quizzes every now and then at the **end** or **beginning** of a class to be added as **2%** bonus mark.

Percentage of Classes Attended	Marks
above 70	8
65-69	7.5
60-64	7
55-59	6.5
50-54	6
45-49	5
40-44	4
below 40	0

PS: Bonus will **only be added** to Assignment and Quiz marks. If you obtain the designated **27%** in quiz and assignments, the bonus will not be added to other areas.

How to get an A/A+ in CSE251?

Time Management: Allocate 10 hrs/wk of *regularly scheduled times* in the week outside of class for CSE251:

- 30 min for **reading** of textbook / slides **before** each class
- 30 min for **studying** online notes **before** each class
- 30 min for **studying** these notes **between** classes
- 75 min for **practicing** problems (Check the practice sheet and previous questions).
- 4-5 hrs/wk for HWs / Assignments.

– In a semester, all lectures total only 30 hrs, which is less than 1 week at a job! It’s up to you to put in the time to learn

– Get a 1” binder (organize lecture notes/HWs/exams)

– Start assignments early. **Do all problems by yourself first.** If you get stuck, form study groups to work on problems together but **ALWAYS** write-up and submit **YOUR OWN** solutions. Do not blindly copy.

– Ask questions and come to office hrs if you get stuck. Don’t let confusion snowball.

How to get an A/A+ in CSE251?

- ***Practice doing problems.*** Get comfortable with the math manipulations and associated physical meaning, and you will find exam problems to be easier
  - HW problems
  - Example problems worked in lecture and online class notes
  - Old exam problems
  - Office hours
- ***Review your prerequisites.***
  - Node analysis, Mesh Analysis, Circuit solving techniques! CSE250
- ***Come to class!!***
  - *HW & Participation are a significant part of your grade*
  - I will discuss topics to be emphasized on exams and give hints about how to approach the more difficult homework problems

How to ~~get an A/A+~~ **pass** in CSE251?

- ***Attendance + Assignments + Quiz + Lab:***

  $8\% \; + \; 12\% \; + \; 25\% \; + \; 15\% \; = 60\%$

  - Suppose, you attend all the classes. Get 83% in Assignments, 83% in Lab, 75% in Quiz. So, you will get:

  $$8 + 10 + 21 + 11.25 = 50.25\% \;\; !!$$

  - Try to do well in these continuous assessments and your road to passing CSE251 will be much easier.

- ***Come to class!!***
  - *HW & Participation are a significant part of your grade*
  - I will discuss topics to be emphasized on exams and give hints about how to approach the more difficult homework problems

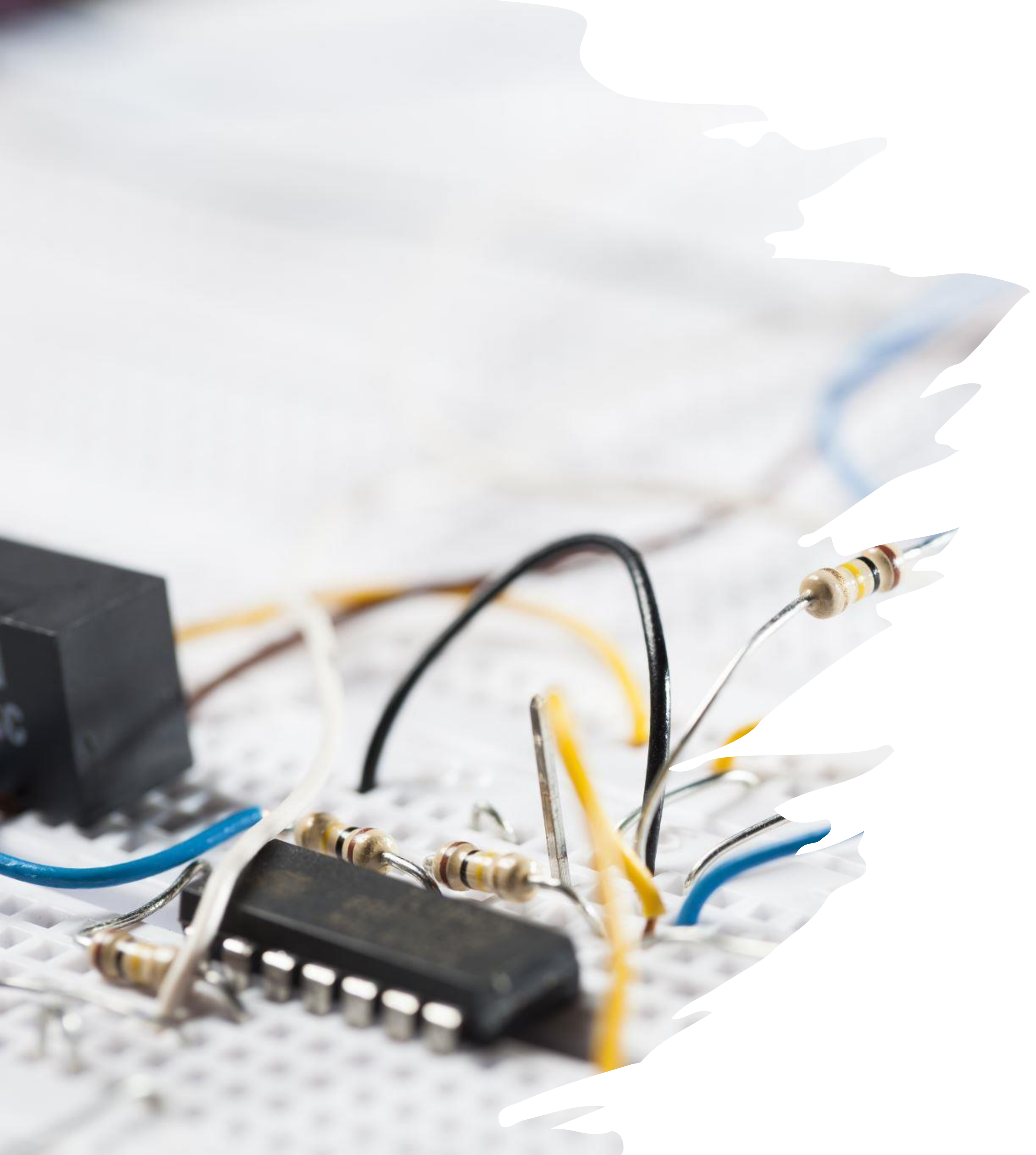
How to approach CSE251?

Write down important information. **(See)**

Visualize - Draw - doodle - interact **(Imagine)**

Think and solve. **(Act)**

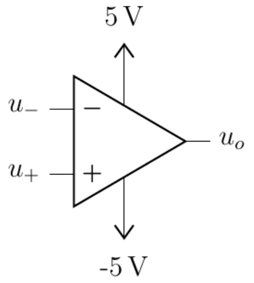
First Day Survey Spring 24



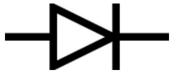
Course outline

Basically, study **four types** of devices.
(Application centric usage)

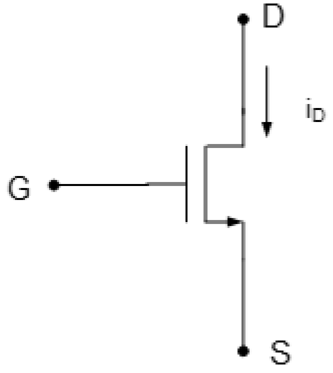
- OP-AMP



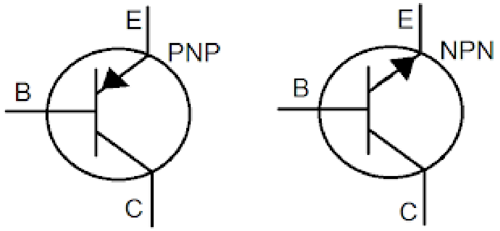
- Diodes



- MOSFET



- BJT



Application: Amplification and Switching

Course Outcome

CO1

Understand and compare the **characteristics** and **operation** of electronic devices

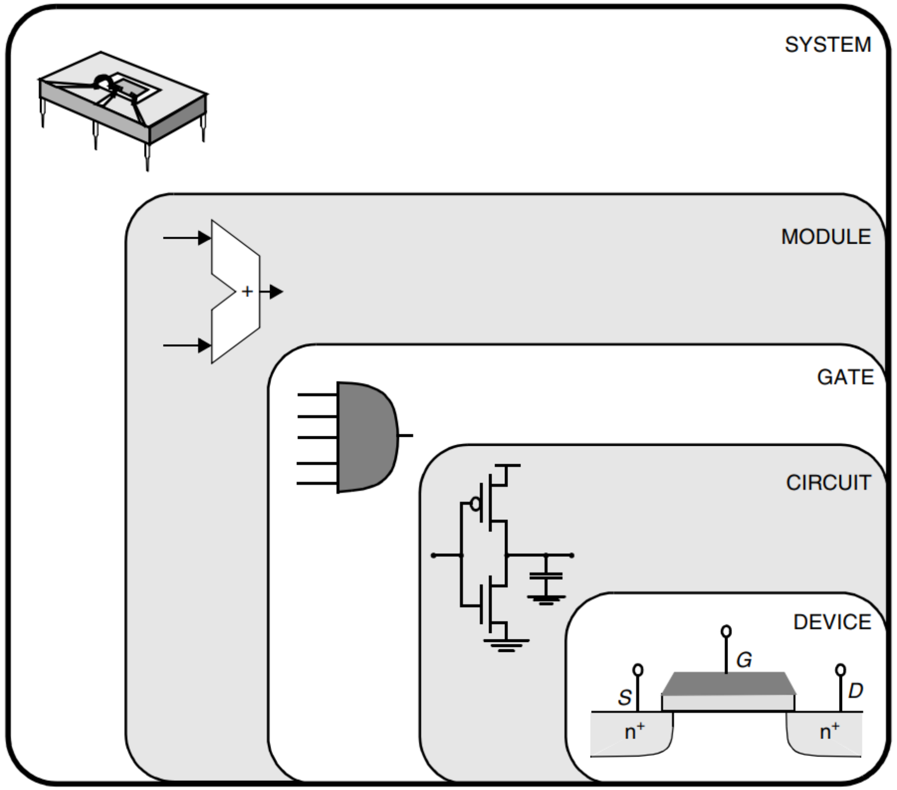
CO2

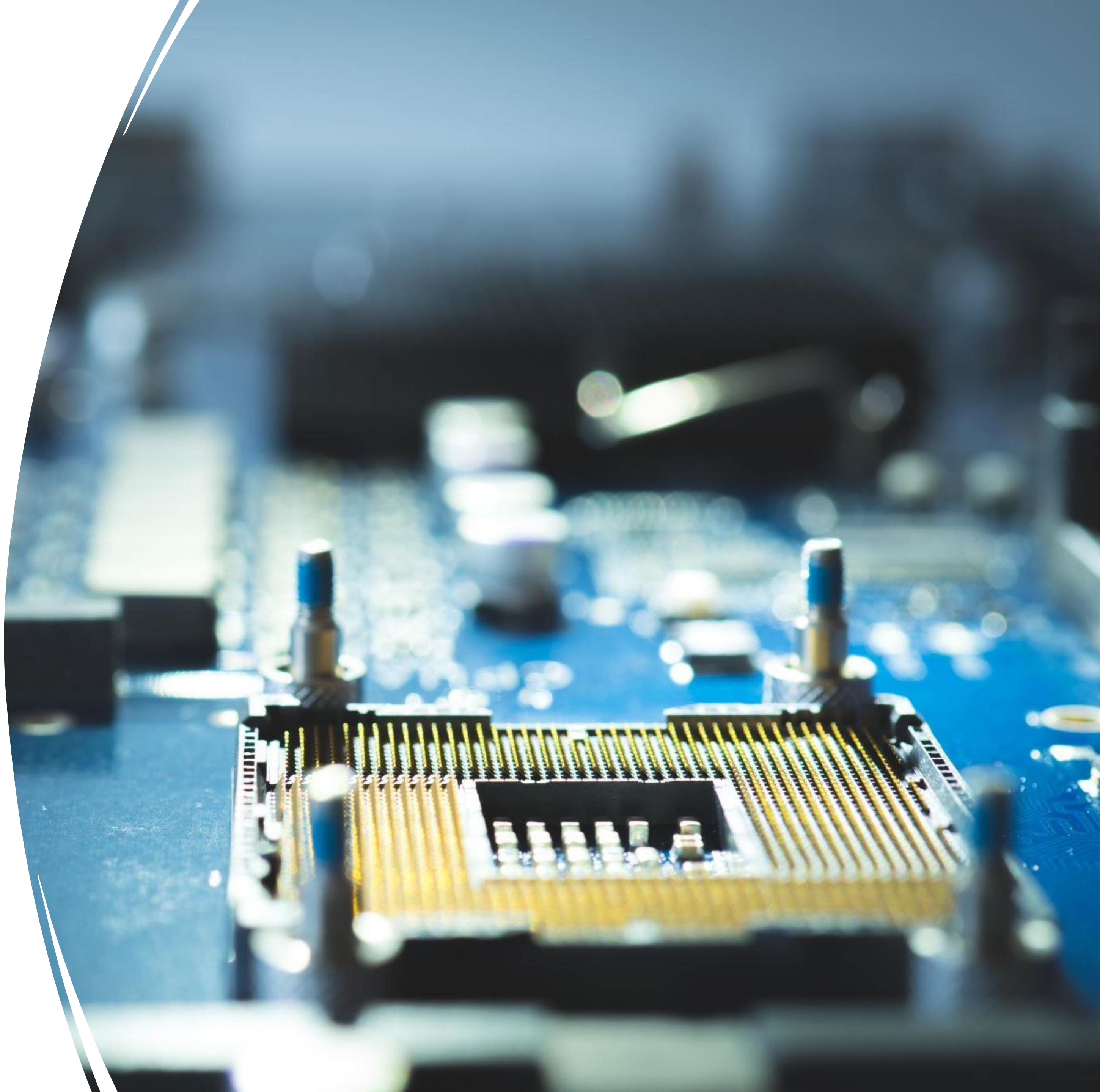
Analyze electronic circuits made from these devices

CO3

Design various electronic circuits for power-generation and analog signal-processing applications.

Abstraction Levels



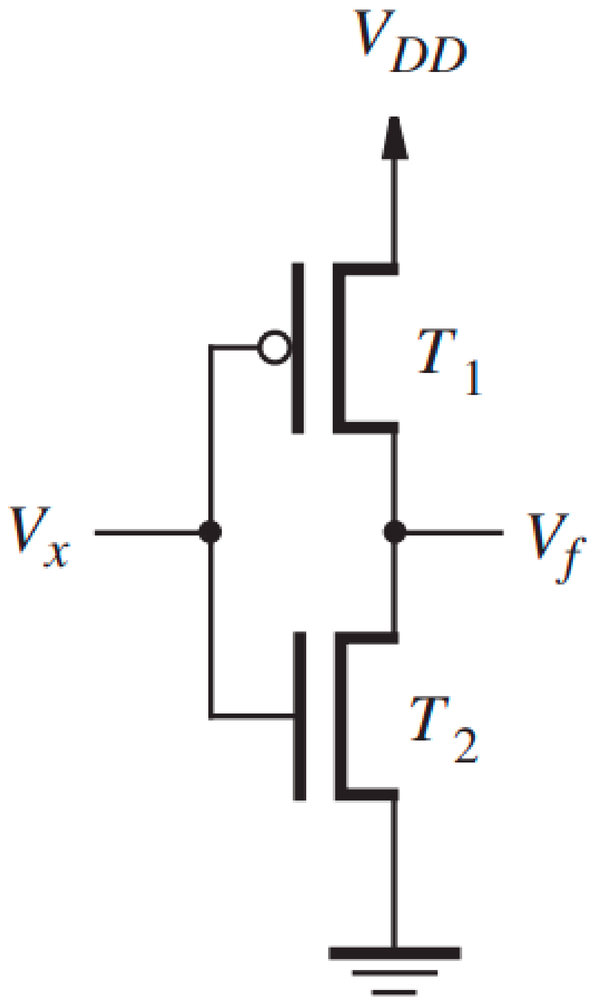


Logic gates –> Electronic Devices

Electronic Devices:

1. Transistors (BJT/MOSFET/ JFET/**FinFET**)
2. Diodes

Amplification and **Switching**



MOSFET realization of a NOT gate.

S. D. Brown and Z. G. Vranesic, *Fundamentals of digital logic with Verilog design*, Third edition. New York: McGraw-Hill Higher Education, 2014.

Historical Perspective

Mechanical gears
(1822 - Difference Engine, Analytical Engine)

- Has it always been like this?
- Eras of Computer evolution:

Electrical switches and
mechanical relays
(1944 - Harvard Mark 1)

1. Gen 1: Mechanical to **Vacuum Tubes** (17th -1940s):
2. Gen 2: **Transistors** (BJT) (1950s): Short-lived
3. Gen 3: **Integrated Circuitry** (1960s - Present)

(1951 – 1959)
Switchover to ***transistors*** from ***vacuum Tubes***

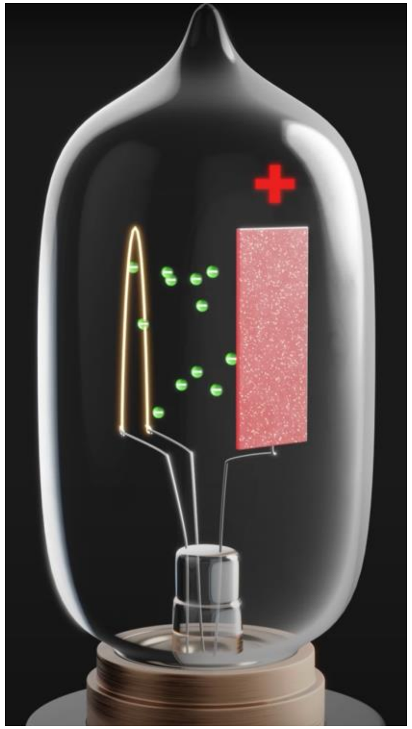
VLSI

Microcomputers -> Laptops, Smartphones

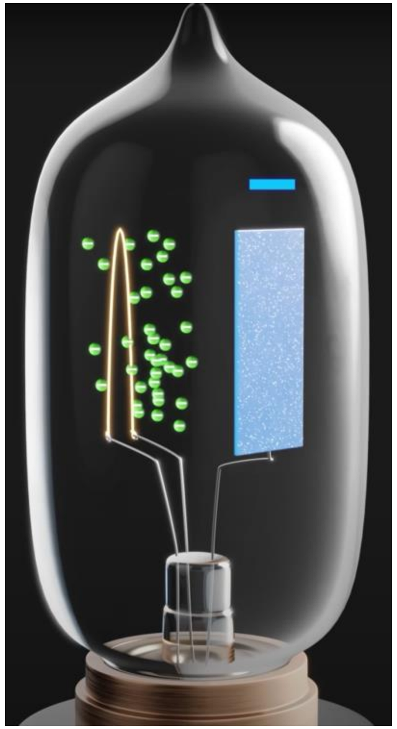
WWI: 1914 - 1918
WWII: 1939 - 1945

History of Computers (uah.edu)

Vacuum Tubes (1946 - ENIAC)



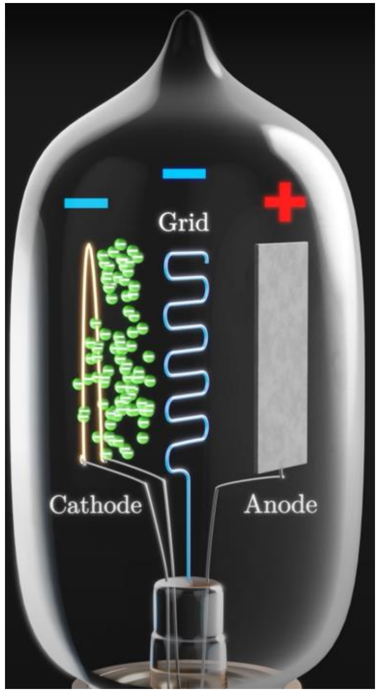
Electron Flow ON

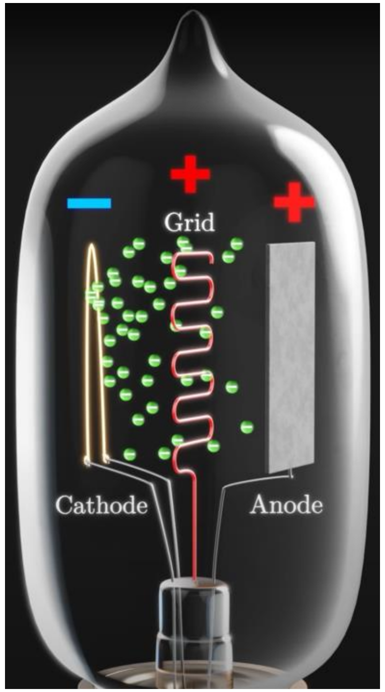


Electron Flow OFF

Thermionic Diode

SWITCHING





Small changes in ***Grid*** voltage translate to large voltages at the Anode

Thermionic Triode

AMPLIFICATION

Computer Systems /Processors with BJT (60s)

Computer System	Year
IBM System/360	1964
DEC PDP Series	1960 (PDP-1), 1965 (PDP-8), 1970 (PDP-11)
Control Data Corporation 6600	1964
IBM System/370	1970
Cray-1	1976

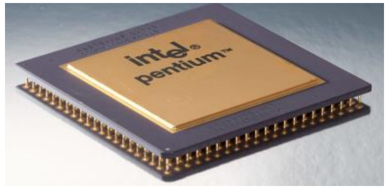
IBM System/360 hybrid BJT circuit

Computer Systems /Processors with MOSFET (70s - Present)

Intel® 4004
1971
10 μm

Intel ® 8086
1978
3 μm

0.8 μm



Intel® Pentium®
1993

Intel® Core™2 Duo
2006
65 nm

22 nm

Intel® Core™
2010

7 nm

AMD Ryzen 5000
2021

Intel® Core™ 12th gen
2021
10 nm

Processor evolution

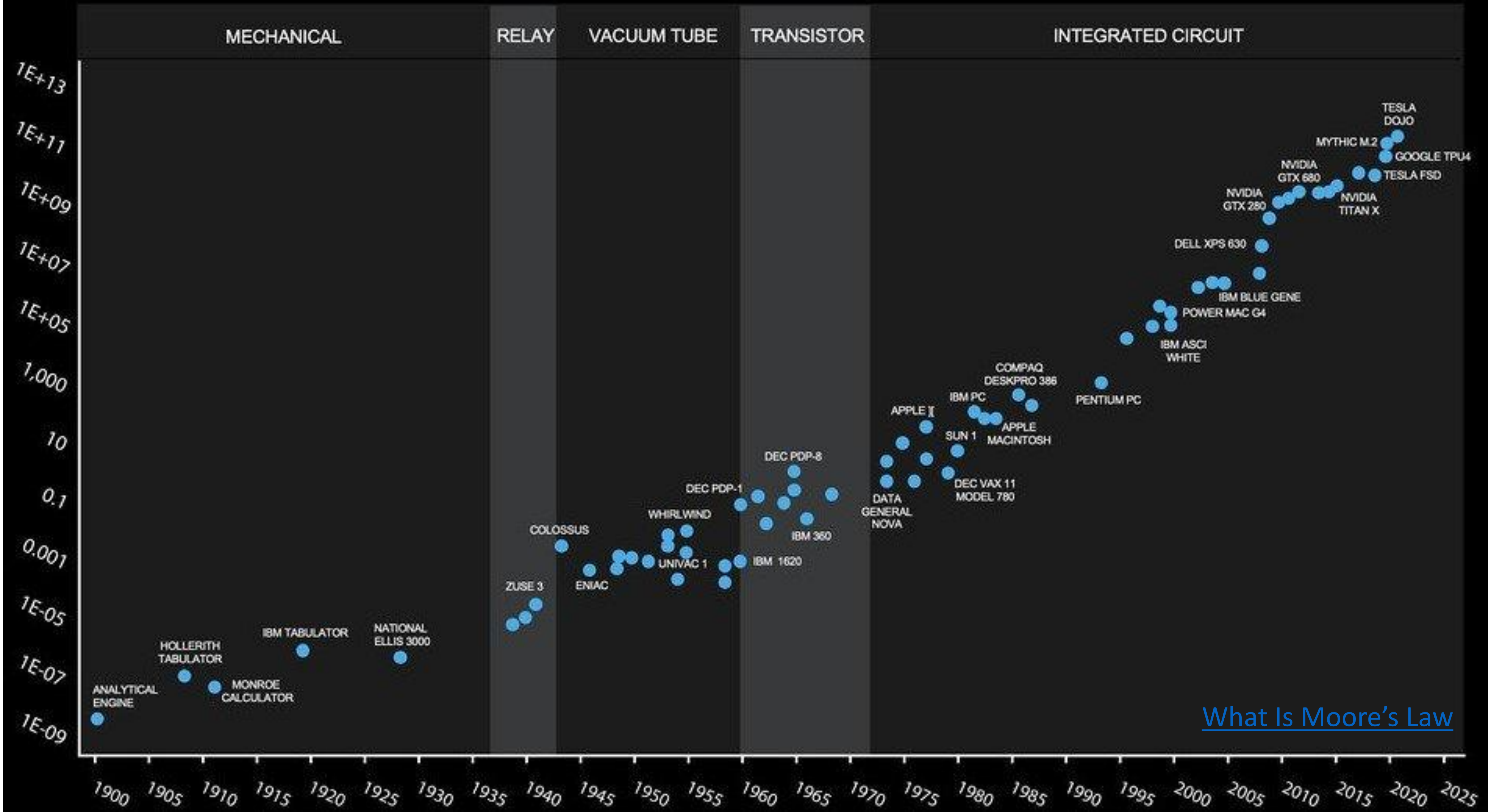
(Red: Feature size)

Moore’s Law

Moore’s Law

The number of transistors in a microchip doubles every two years

122 YEARS OF MOORE'S LAW



What Is Moore's Law

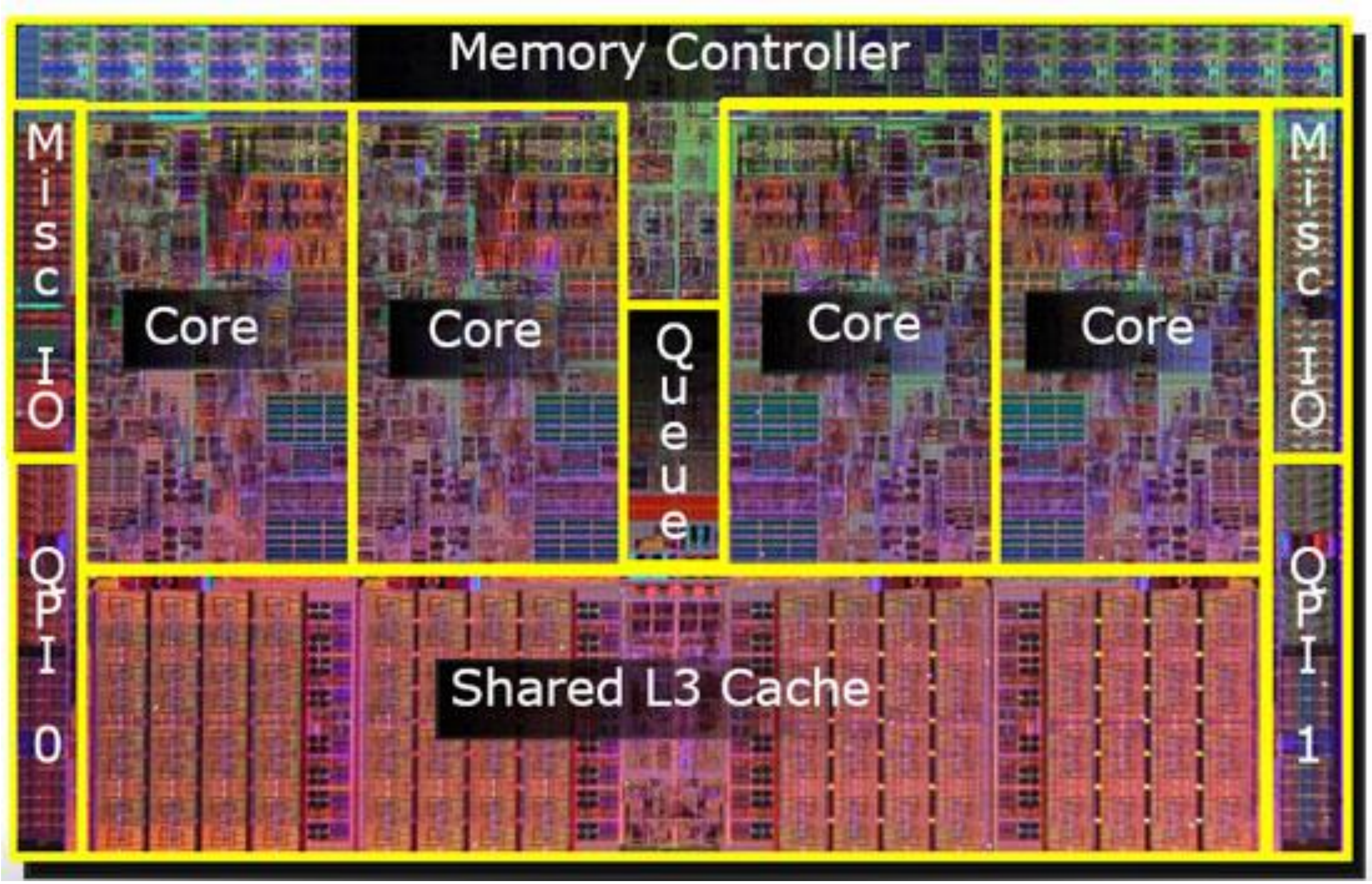
Current scenario and the future

- ~~Ongoing chip shortage!~~
- Two type of companies:
  1. **Fabless** design companies: AMD
     Apple etc.
  2. **Foundries**: Intel
     TSMC
     Samsung
     Global Foundries

Moore's Law is approaching an end.
Possible alternatives for the future:

1. Spintronics
2. Photonics
3. Nano-electronics (Quantum)

An Integrated Circuit Layout of a Processor



List of resources used in this slide

- History of Computers
- More about Vacuum Tubes – Veritasium YouTube
- More information about Semiconductor chip industry
- Moore’s Law

Thank You

CSE251: Electronic Devices and Circuits

Lecture 1

Alt. Representation, CSE250 Review

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Outline

- Alternative Circuit Representation – Line diagrams
- CSE250 Review
  - KCL, KVL
  - Series, Parallel resistor network – Voltage Division, Current division
  - Examples
- IV Characteristics
  - Linear IV – Resistors, Voltage Source, Current Source, SC, OC.
  - Non-Linear IV – Piecewise Linear Model

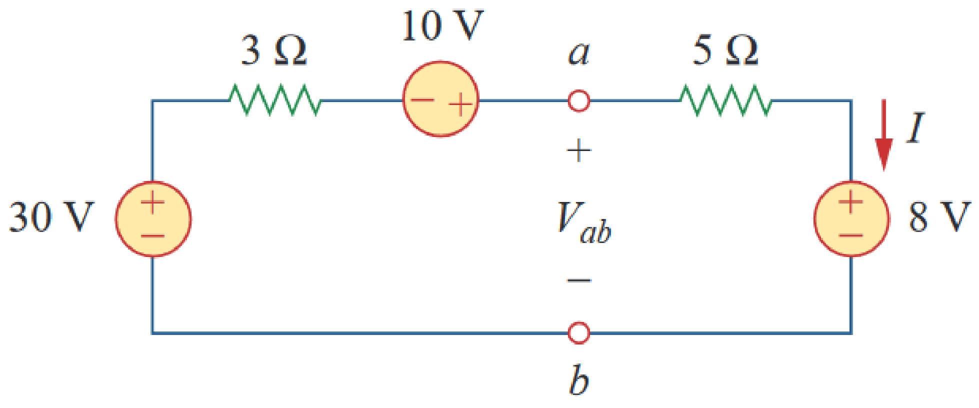
Alternative Circuit Representation: Line diagrams

Steps to decompose circuits to line diagram

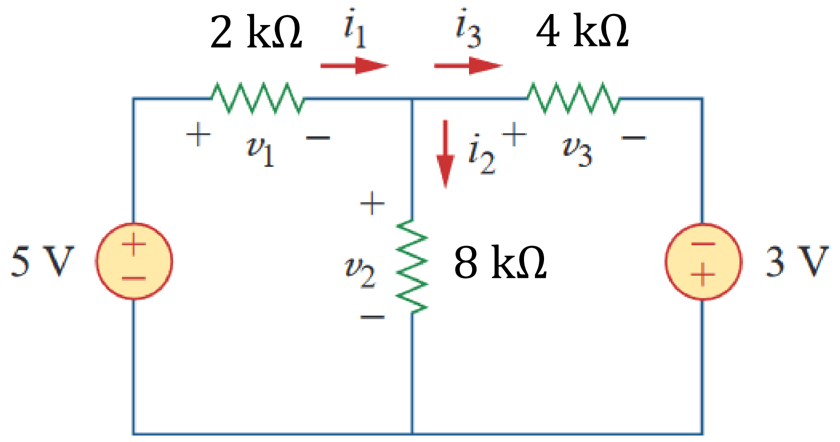
1. Set a ground so that number of **floating voltage** sources are minimized.
2. Detach the ground **from the voltage source**.
3. Convert the non-floating voltage sources (~~current sources~~) into:
   - Arrow : (→) **Fixed/Constant voltage source**
4. Keep passive elements as they are.

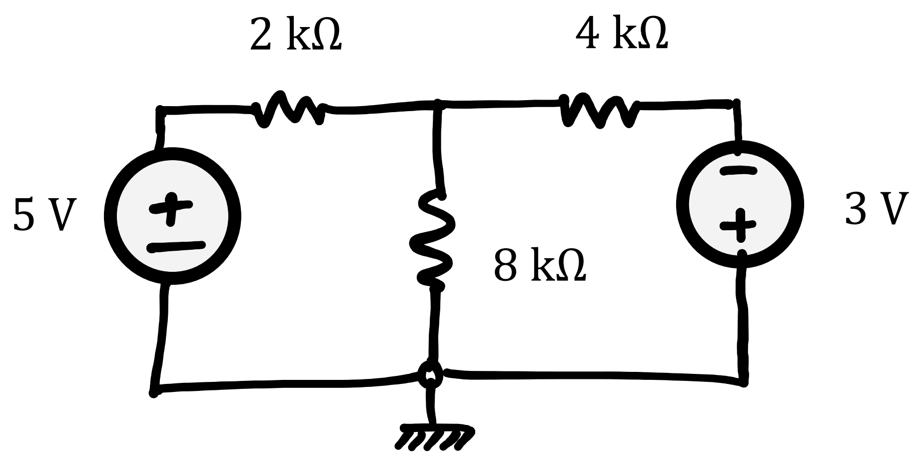
Floating voltage sources:

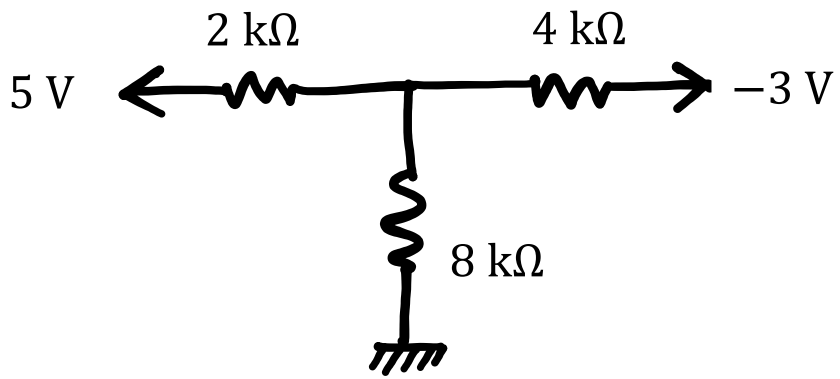
Voltage sources which are **not connected the ground** terminal. In the diagram, the **10 V** voltage source is floating



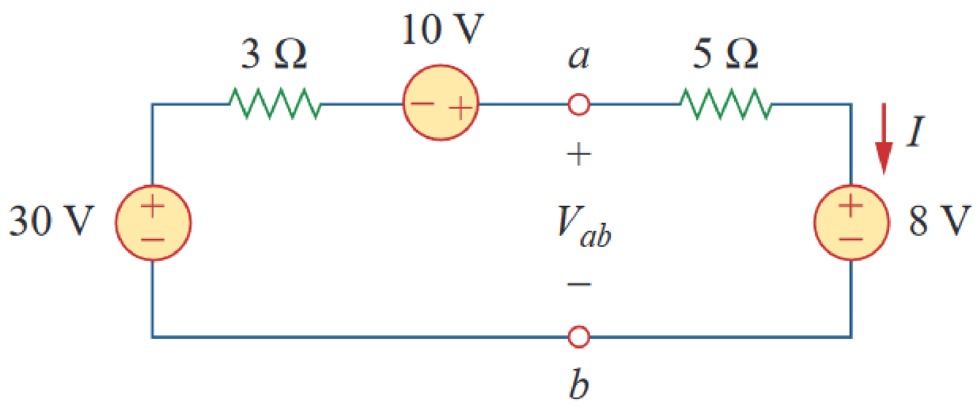
Line diagrams: Example 1

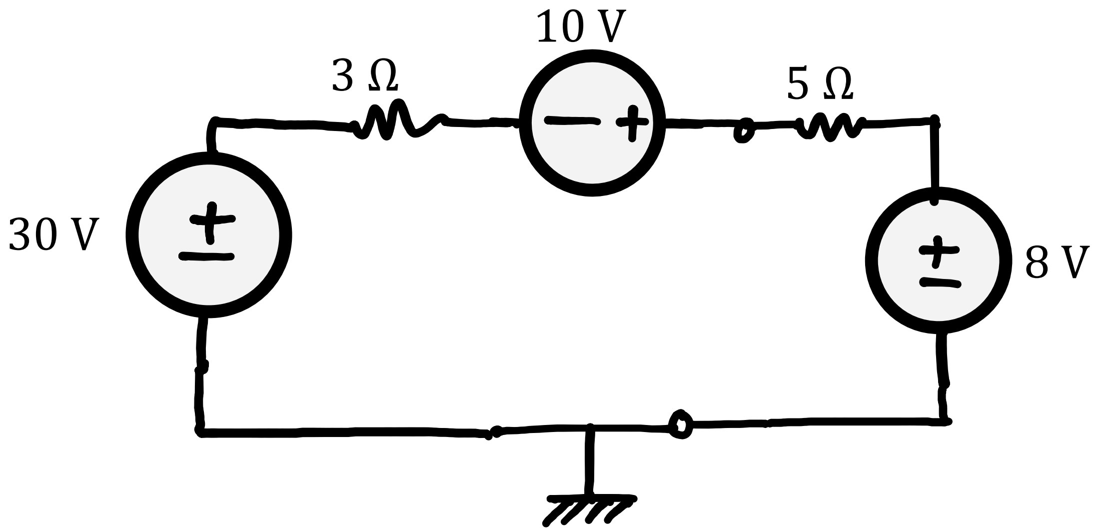


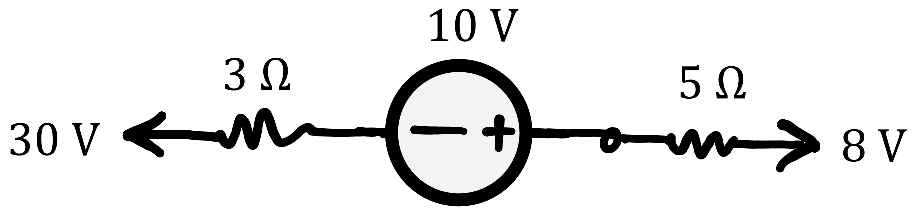




Line diagrams: Example 2

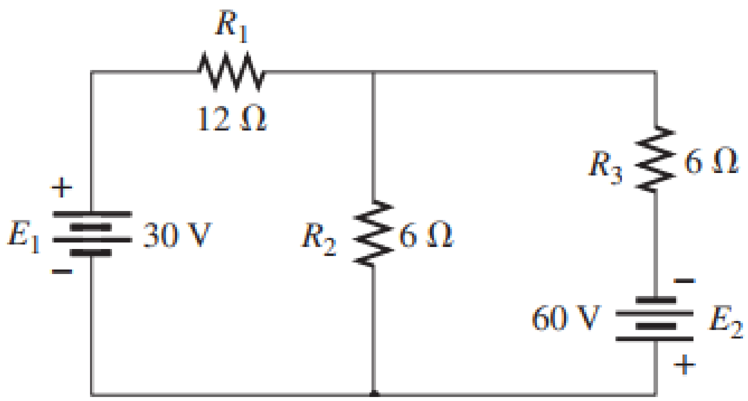






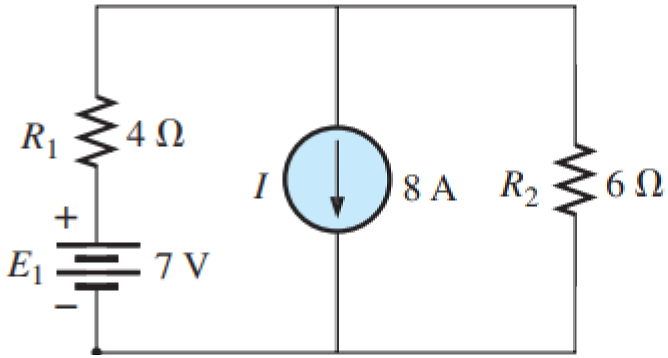
More Examples

Difficulty : 2/5



Example: 2

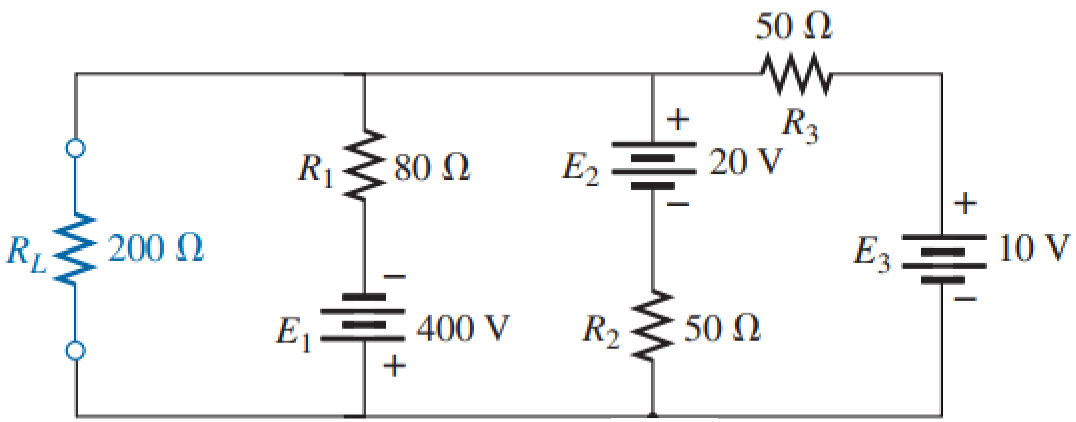
Difficulty : 3/5



Example: 3

More Examples

Difficulty : 4/5



Example: 4

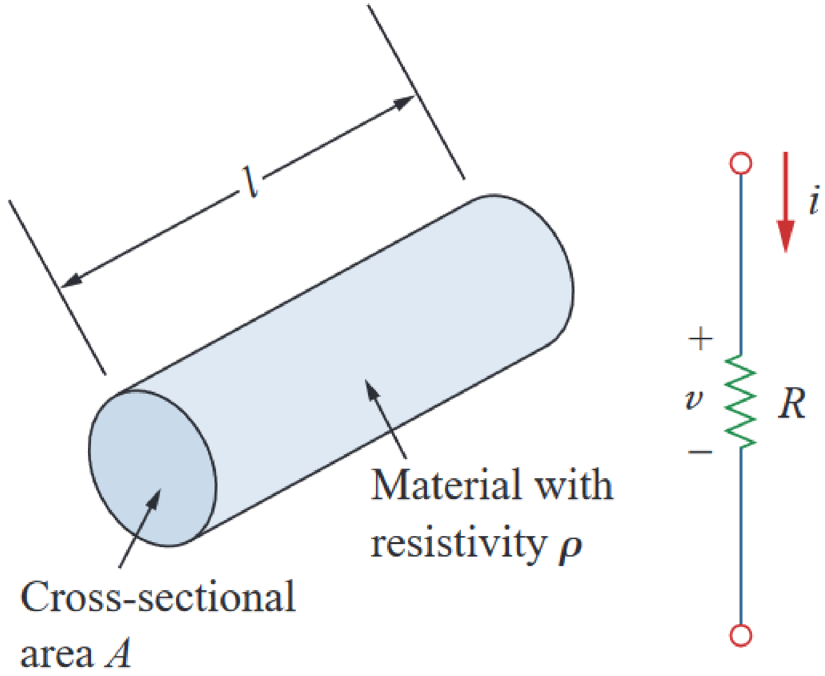
Step – (4) Make all the active elements (dc/ac type, voltage/~~current~~ sources) into single terminals (arrows/circles) using the voltages you wrote as much as you can [***THERE MIGHT BE CASES WHERE YOU CAN'T DO THAT***]

The fundamentals …

Ohm’s Law –

- the voltage $\boldsymbol{v}$ across a resistor is **directly proportional** to the current $\boldsymbol{i}$ flowing through the resistor ($\boldsymbol{R}$)

$$\boldsymbol{v} \propto \boldsymbol{i}$$
$$\boldsymbol{v} = \boldsymbol{i}\boldsymbol{R}$$



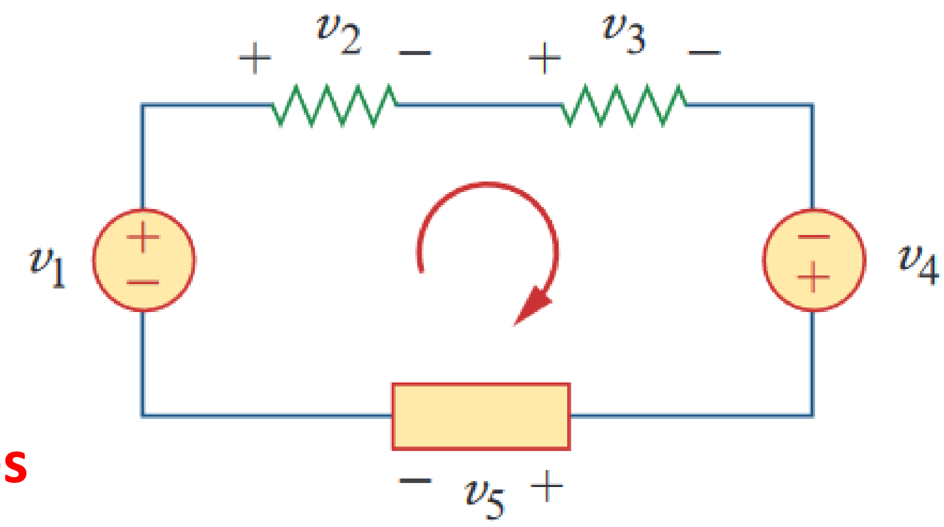
KVL: Kirchhoff's voltage law

The <u>algebraic sum</u> of all **voltages** around **a closed path (or loop)** is zero.

$$-\boldsymbol{v_1} + v_2 + v_3 - \boldsymbol{v_4} + v_5 = 0$$

$$v_2 + v_3 + v_5 = \boldsymbol{v_1} + \boldsymbol{v_4}$$

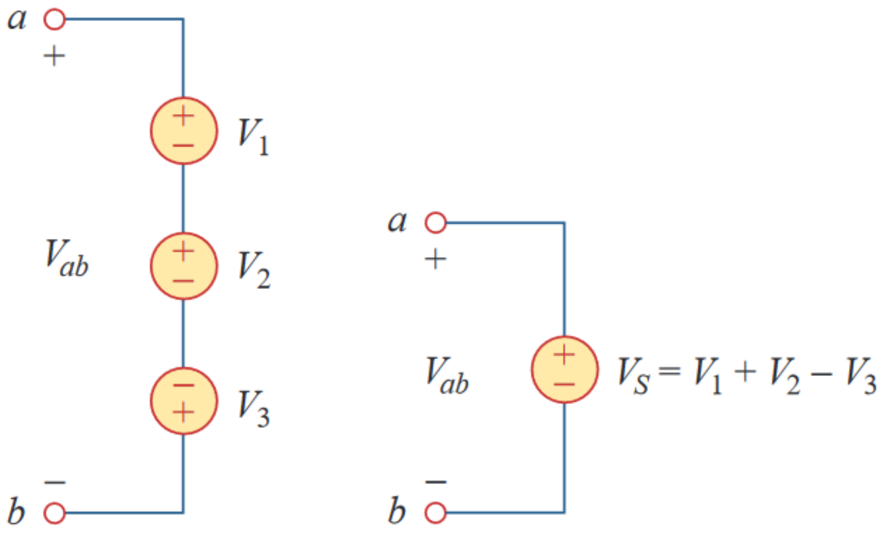
Sum of voltage drops = **Sum of voltage rises**



KVL: Kirchhoff's voltage law

$$-V_{ab} + V_1 + V_2 - V_3 = 0$$

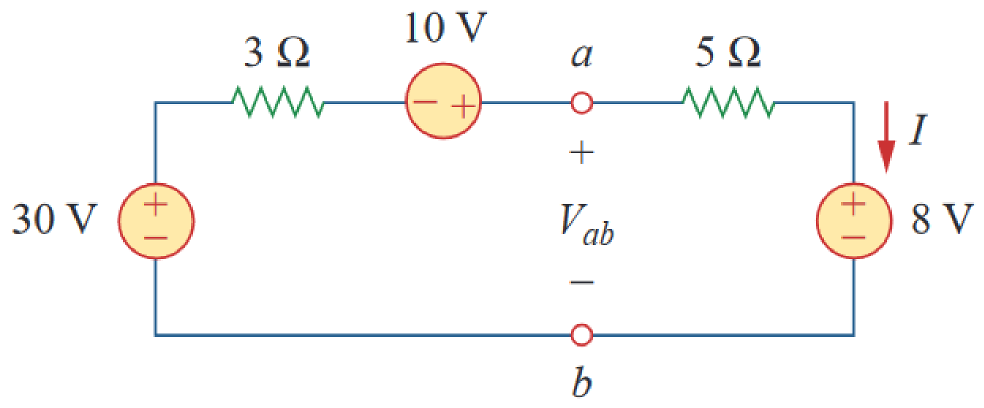
$$V_{ab} = V_1 + V_2 - V_3$$



Equivalent Circuits

KVL – Example 1

Find $\boldsymbol{I}$ and $\boldsymbol{V_{ab}}$ in the circuit



Solution:

KVL

$$-30 + 3\boldsymbol{I} - 10 + 5\boldsymbol{I} + 8 = 0$$

$$\boldsymbol{I} = \frac{32}{8}\,\mathrm{A} = 4\ \mathrm{A}$$

KVL

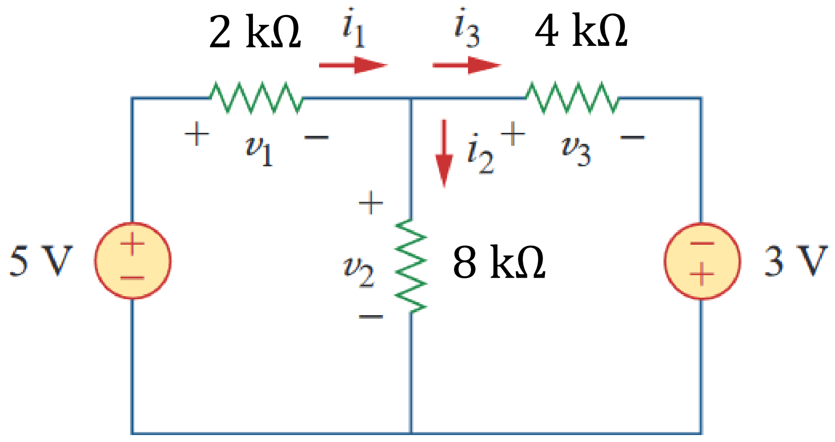
$$-V_{ab} + 5\boldsymbol{I} + 8 = 0$$

$$\boldsymbol{V_{ab}} = 28\ \mathrm{V}$$

Tip: If you find resistance values in **kΩ** instead of **Ω**, don't convert the **kΩ** values to **Ω**. Just find currents in **mA** instead of **A**.

KVL – Example 2

Find $\boldsymbol{v_1}, \boldsymbol{v_2}, \boldsymbol{v_3}, \boldsymbol{i_1}, \boldsymbol{i_2}$ and $\boldsymbol{i_3}$ in the circuit



Solution:

KVL in first loop

$$-5 + 2\boldsymbol{i_1} + 8(\boldsymbol{i_1} - \boldsymbol{i_3}) = 0$$

$$10\boldsymbol{i_1} - 8\boldsymbol{i_3} = 5$$

KVL in second loop

$$-8(\boldsymbol{i_1} - \boldsymbol{i_3}) + 4\boldsymbol{i_3} - 3 = 0$$

$$-8\boldsymbol{i_1} + 12\boldsymbol{i_3} = 3$$

Solving:

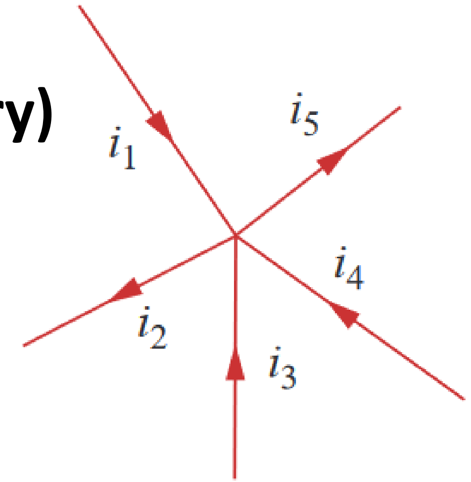
$$i_1 = 1.5 \text{ mA}$$
$$i_3 = 1.25 \text{ mA}$$
$$i_2 = i_1 - i_3 = 0.25 \text{ mA}$$

$$v_1 = 3 \text{ V}$$
$$v_2 = 2 \text{ V}$$
$$v_3 = 5 \text{ V}$$

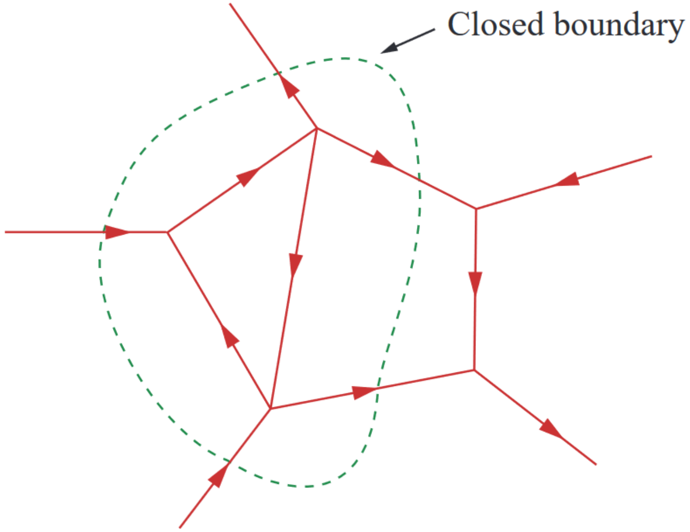
Tip: If you find resistance values in **kΩ** instead of **Ω**, don't convert the **kΩ** values to **Ω**. Just find currents in **mA** instead of **A**.

KCL: Kirchoff's Current Law

The <u>algebraic sum</u> of the **currents** entering a **node (closed boundary)** is equal to the sum of the currents leaving the node.



$$i_1 + (-i_2) + i_3 + i_4 + (-i_5) = 0$$

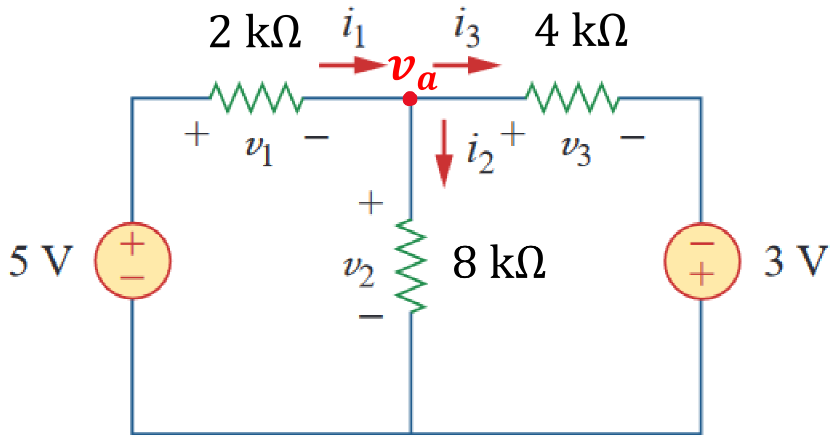


Current Entering node: **Positive**
Current Exiting node: **Negative**

Or vice versa…

KCL- Example 1

Find $\boldsymbol{v_1}, \boldsymbol{v_2}, \boldsymbol{v_3}, \boldsymbol{i_1}, \boldsymbol{i_2}$ and $\boldsymbol{i_3}$ in the circuit



Solution:

KCL in node $\boldsymbol{v_a}$. (PS: $\boldsymbol{v_a = v_2}$)

$$\frac{5 - \boldsymbol{v_2}}{2} - \frac{\boldsymbol{v_2} - (-3)}{4} - \frac{\boldsymbol{v_2} - 0}{8} = 0$$

$$v_2\left(-\frac{1}{2} - \frac{1}{4} - \frac{1}{8}\right) = -\left(\frac{5}{2} - \frac{3}{4}\right)$$

$$\boldsymbol{v_2} = \frac{7}{4} \cdot \frac{8}{7} \text{ V} = 2 \text{ V}$$

$$\boldsymbol{v_1} = 5 - v_2 = 3 \text{ V}$$

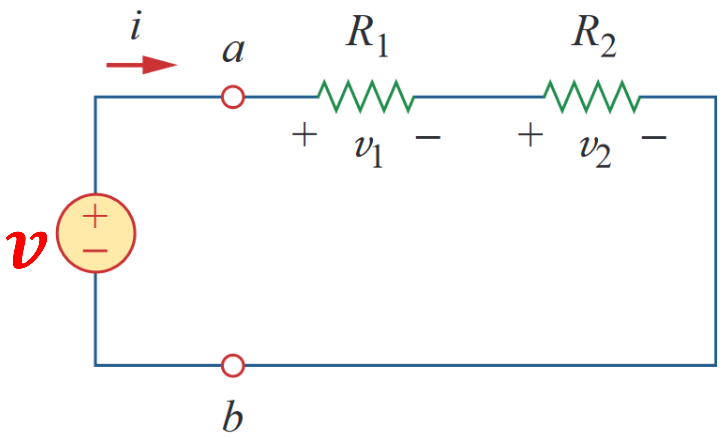
$$\boldsymbol{v_3} = v_2 - (-3) = 5 \text{ V}$$

Series Resistors and Voltage Division

The **equivalent resistance** of any number of resistors **connected in series** is the sum of the individual resistances.

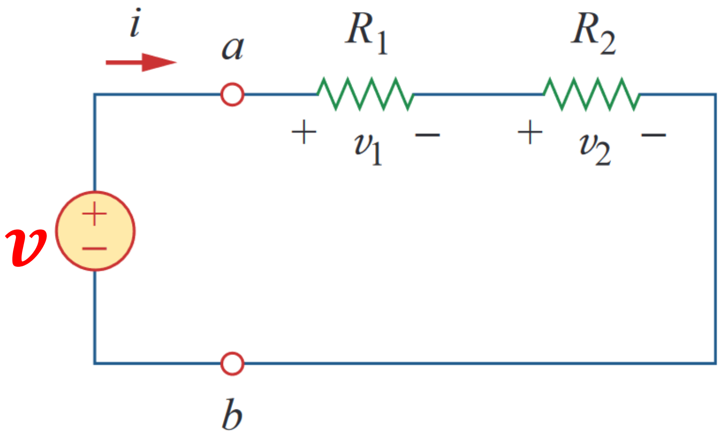
Principle of voltage division

Source voltage v - is divided among the resistors in direct proportion to their resistances; the larger the resistance, the larger the voltage drop.



$$v_1 = \frac{R_1}{R_1 + R_2} v \qquad v_2 = \frac{R_2}{R_1 + R_2} v$$

Line diagram: Example 3



$$\frac{R_1}{R_1 + R_2} v$$

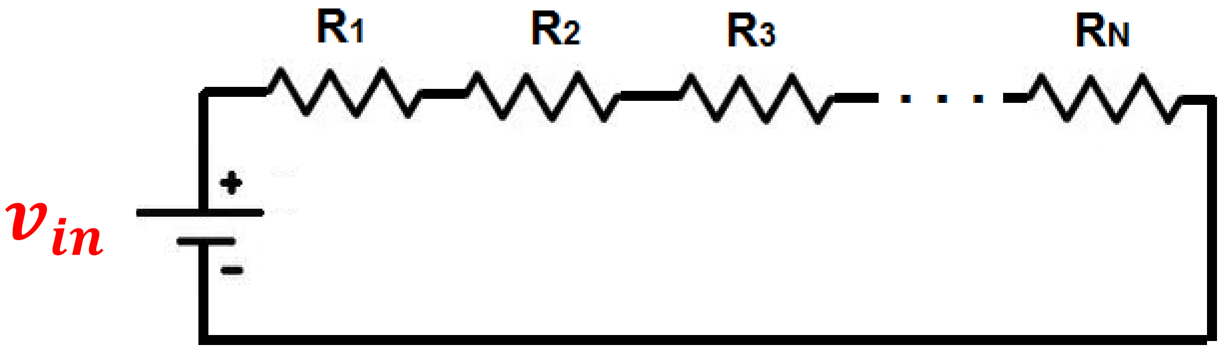
$$v_2 = \frac{R_2}{R_1 + R_2} v$$

Series Resistors and Voltage Division

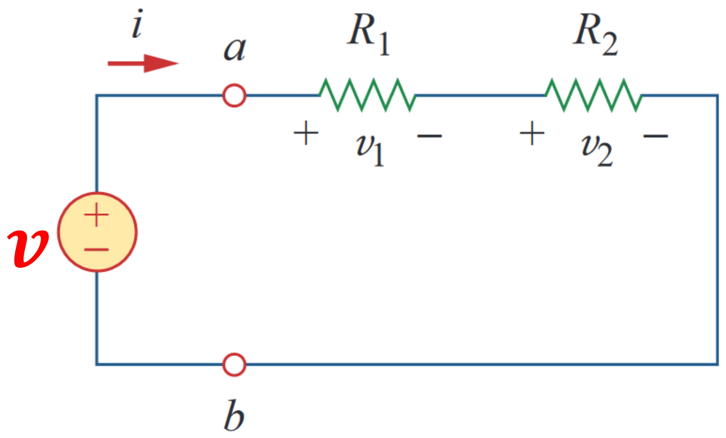
- If there are $\boldsymbol{N}$ resistors in series, the voltage across the $\boldsymbol{i}$ –th resistor is given by,

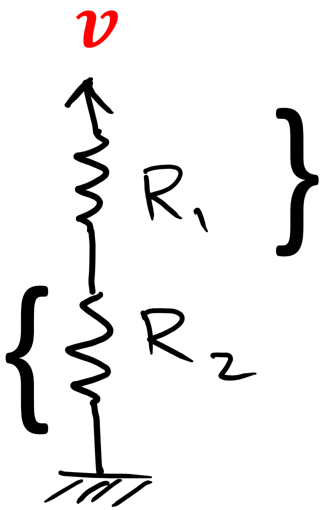
As $\boldsymbol{V} \propto \boldsymbol{R}$

$$v_i = \frac{\boldsymbol{R_i}}{\sum_i R_i} \boldsymbol{v_{in}}$$



Line diagram: Example 3





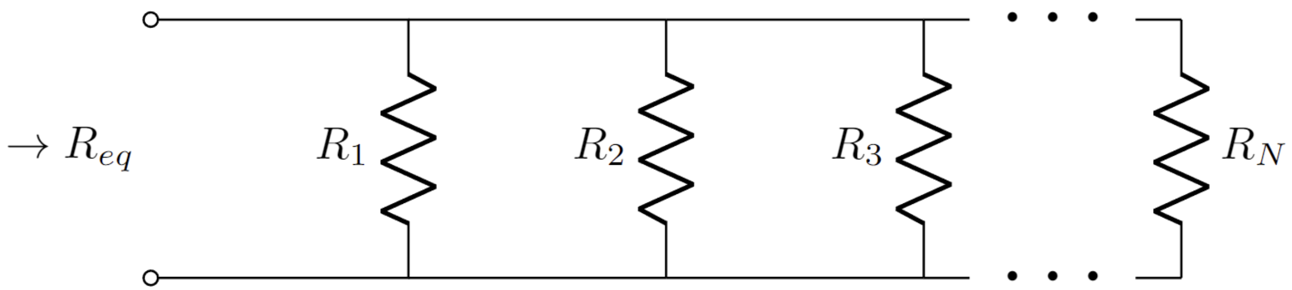
KVL (acts along a line instead of a loop)

$$v - iR_1 - iR_2 = 0$$

Parallel Resistors and Current Division

The **equivalent resistance** of any number of resistors connected in **parallel** is the inverse of the sum of the individual **conductances**.

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots \frac{1}{R_N}$$



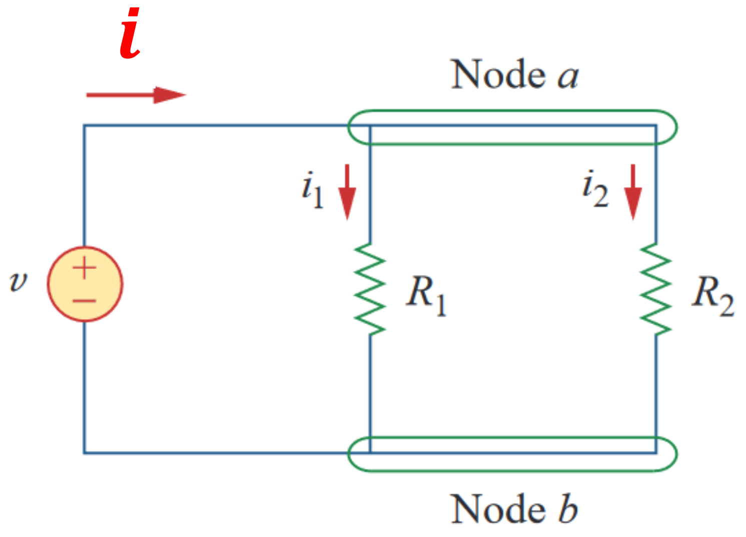
Simplification for the case when $R_1 = R_2 = R_3 \cdots = R_N$

$$R_{eq} = \frac{R_1}{N}$$

Parallel Resistors and Current Division

The **equivalent resistance** of any number of resistors connected in **parallel** is the inverse of the sum of the individual **conductances**.

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} \qquad R_{eq} = R_1||R_2 = \frac{R_1 R_2}{R_1 + R_2}$$



Simplification for the case when $R_1 = R_2$

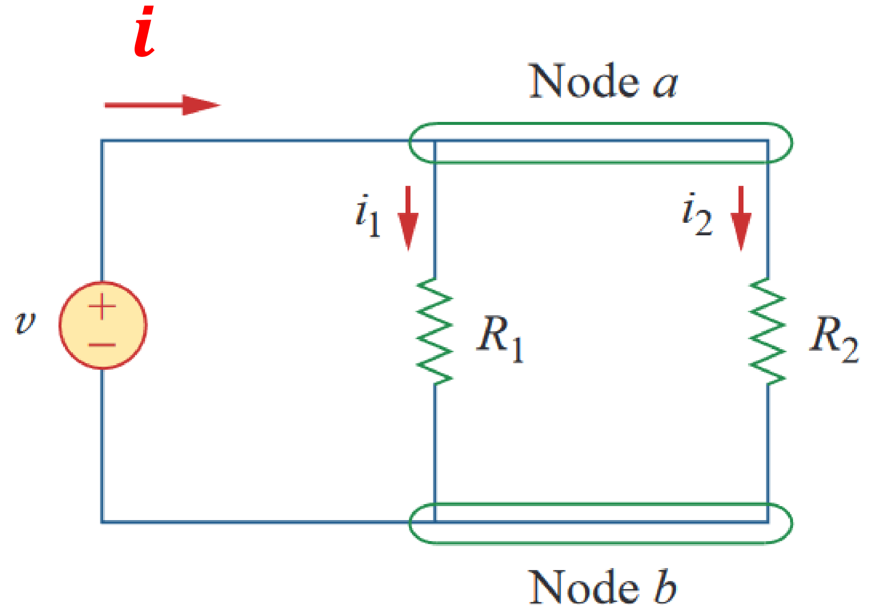
$$R_{eq} = \frac{R_1}{2}$$

Parallel Resistors and Current Division

The **equivalent resistance** of any number of resistors connected in parallel is the inverse of the sum of the individual **conductances**.

Principle of current division

Source current i - is divided among the resistors in direct inverse proportion to their resistances; the larger the resistance, the larger the voltage drop.



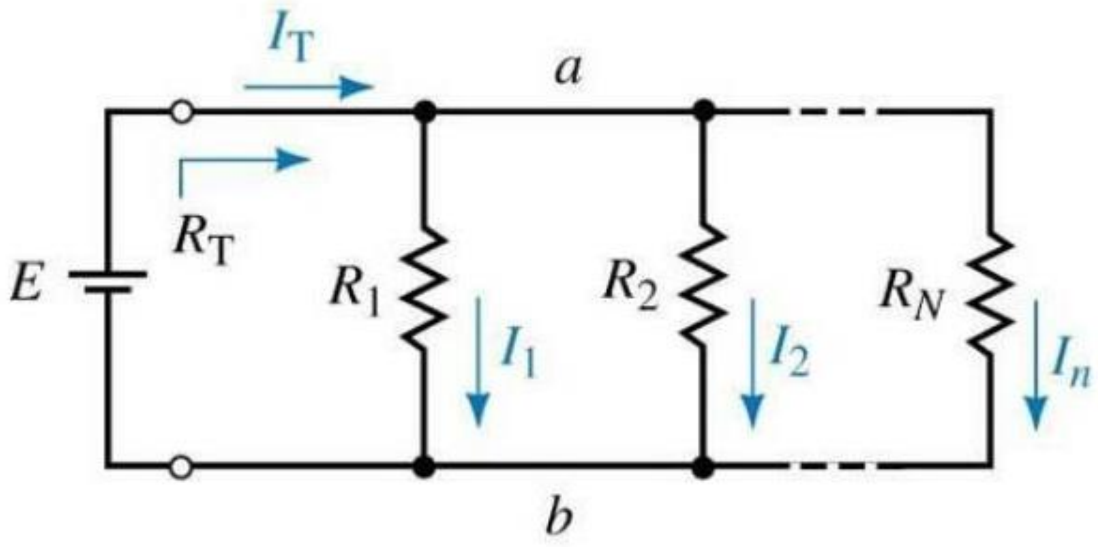
$$i_1 = \frac{1/R_1}{1/R_1 + 1/R_2} i \qquad i_2 = \frac{1/R_2}{1/R_1 + 1/R_2} i$$

Parallel Resistors and Current Division

- If there are $\boldsymbol{N}$ resistors in parallel, the current through the $\boldsymbol{i}$ –th resistor is given by, $i \in \{1,2,3, \cdots N\}$

As $\boldsymbol{I} \propto \frac{\mathbf{1}}{\boldsymbol{R}}$

$$I_i = \frac{\mathbf{1}/\boldsymbol{R_i}}{\sum_i 1/R_i} \boldsymbol{I}_{\mathbf{T}}$$



Thank You