2/18/2019

Electric Circuits
Lecture 1 Introduction

EE2210, Spring 2019

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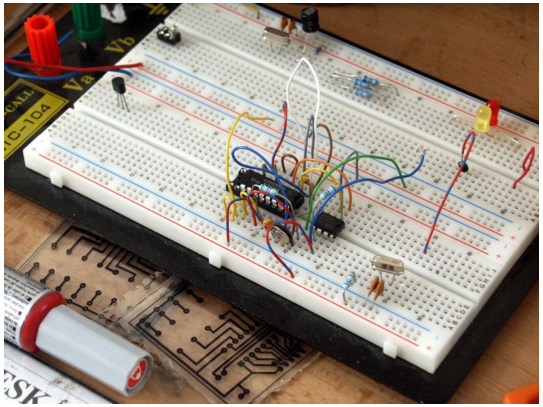
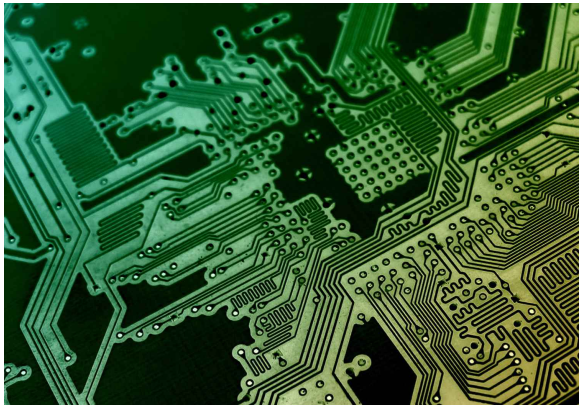
Lecture Outline

- Course introduction
- Lumped circuit abstraction (Chapter 1 in the textbook)
  - How the lumped circuit abstraction derives from Maxwell's equations.
  - Abstraction simplifies the analysis of complicated systems.





Course Info

- Instructor: Jenny Yi-Chun Liu 劉怡君
- Email: jennyliu@gapp.nthu.edu.tw
- Time & location: Mon 10:10am-12pm, Wed 9-9:50am @ Delta 215
- Office hours: by appointment
- Course website: iLMS (notes and videos)
- TAs: 張賀鈞、張斐青、蔡嘉展、鄭宇維
- TA session: TBD Wed 6-8pm @ EECS 518
- Feedback anytime!

What is this class all about?

- This course introduces the fundamental circuit concepts and circuit analysis techniques.
- Main topics include resistive networks, circuit laws and analytical techniques, linear circuit analysis, energy storage elements, first-order and second-order circuits, sinusoidal steady state, and MOSFET amplifiers.

Course Goals

- Understand the basic circuit principles on which the design of electronic systems is based.
- Analyze and design simple electronic circuits in time and frequency domains.
- Analyze the circuits with energy storage elements.
- Understand the concept of employing models to represent nonlinear and active elements.

Weekly Schedule (Tentative)

Week	Date	Lecture
1	Feb 18	Introduction
	Feb 20	Resistive networks
2	Feb 25	No class
	Feb 27	
3	Mar 4	Resistive networks
	Mar 6	Network theorems
4	Mar 11	
	Mar 13	MOSFET amplifiers
5	Mar 18	
	Mar 20	First-order circuits
6	Mar 25	
	Mar 27	
7	Apr 1	
	Apr 3	
8	Apr 8	No class
	Apr 10	First-order circuits
9	Apr 15	Midterm
	Apr 17	Energy and power
10	Apr 22	Energy and power
	Apr 24	Second-order circuits
11	Apr 29	
	May 1	
12	May 6	
	May 8	
13	May 13	Sinusoidal steady state
	May 15	
14	May 20	Impedance
	May 22	
15	May 27	No class
	May 29	No class/Quiz
16	Jun 3	Time domain analysis
	Jun 5	
17	Jun 10	Operational amplifiers
	Jun 12	
18	Jun 17	Final exam

Course Materials

- Textbooks
  - Lecture notes (will be posted online)
  - Anant Agarwal and Jeffrey H. Lang, *Foundations of Analog and Digital Electronic Circuits*, Morgan Kaufmann Publisher, Elsevier.
- Reference materials
  - Richard C. Dorf and James A. Svoboda, *Introduction to Electric Circuits*, Wiley.
  - James W. Nillson and Susan A. Riedel, *Electric Circuits*, Pearson Prentice Hall.
  - Others available on course website.

Course Grading

- Three items make the final grade.
  - Quizzes: 30% (In-class)
  - Midterm: 35%
  - Final: 35%
  - Calculator allowed. Closed book.
- Please comply with the honor code.

What is Engineering?

- ‘Engineering is the purposeful use of science’
  - Science provides an understanding of natural phenomena.
  - Electrical engineering is one of many engineering fields.
  - Electrical engineering is the purposeful use of Maxwell’s equations for electromagnetic phenomena.
- Maxwell’s Equations

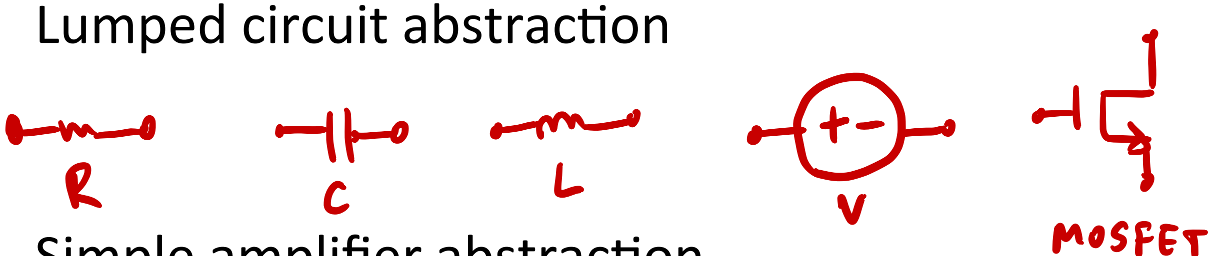
$\nabla \cdot \mathbf{E} = \dfrac{\rho}{\epsilon_0}$	Gauss’s law for electricity
$\nabla \cdot \mathbf{B} = 0$	Gauss’s law for magnetism
$\nabla \times \mathbf{E} = -\dfrac{\partial \mathbf{B}}{\partial t}$	Faraday’s law of induction
$\nabla \times \mathbf{B} = \mu_0 \epsilon_0 \dfrac{\partial \mathbf{E}}{\partial t} + \mu_0 \mathbf{J}$	Ampere’s law (extended)
$\nabla \cdot \mathbf{J} = -\dfrac{\partial \rho}{\partial t}$	Continuity equation

What is EE2210 about?

- Gainful employment of Maxwell's Equations.
- From electrons to digital gates and operational amplifiers.
  - Nature as observed in experiments

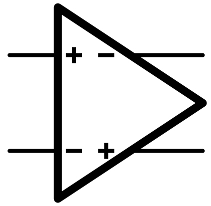
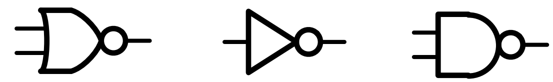
v	3	6	9	12	…
i	0.1	0.2	0.3	0.4	…

  - Physical laws or 'abstractions'
    - Maxwell's Equations
    - Ohm's Law $v = R \cdot i$
  - Lumped circuit abstraction



  - Simple amplifier abstraction
    - Electronics (EE2255)

Analog and Digital Abstractions

Analog 	**Digital** 

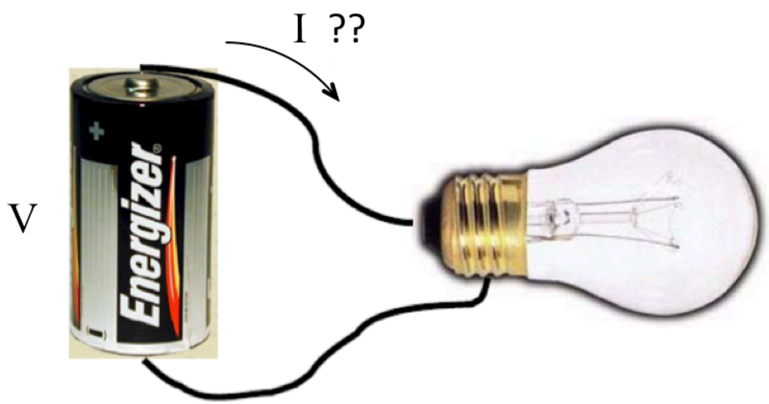
Operational amplifier
Filters
Analog subsystems
  Modulators
  Oscillators
  RF amplifiers
  Power supplies
	Combinational logic
	Clocked digital abstraction
	Instruction set abstraction
	Programming languages
	Software systems

AIC-I (EE3235) AIC-II (EE4280) Introduction to IC Design (EE4290) Power Electronics (EE4830) Power System I (EE4710)	Logic Design (EE2280) Intro. to Programming (EE2310) Data Structures (EE2410) Microprocessor Systems (EE2401) Computer Architecture (EE3450)
Embedded System Laboratory (EE2405) Special Topic on Implementation (EE3900)	

Lumped Circuit Abstraction

- Jump from physics to EE.

- We wish to answer the question: what is the current flowing through the bulb?



We could do it the Hard Way…

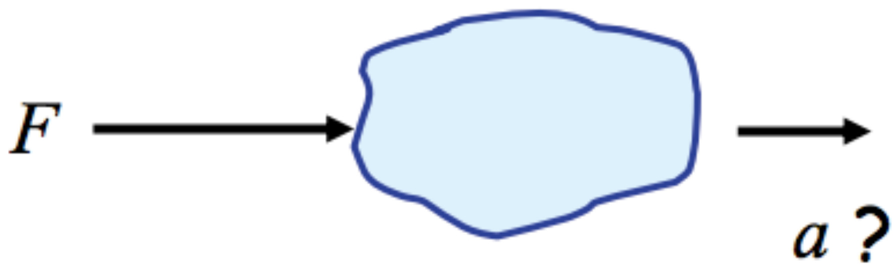
- Apply Maxwell's equations

DIFFERENTIAL FORM	INTEGRAL FORM	POPULAR NAME
$\nabla \cdot \mathbf{E} = \frac{\rho}{\epsilon_0}$	$\oint \mathbf{E} \cdot d\mathbf{S} = \frac{q}{\epsilon_0}$	Gauss's law for electricity
$\nabla \cdot \mathbf{B} = 0$	$\oint \mathbf{B} \cdot d\mathbf{S} = 0$	Gauss's law for magnetism
$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$	$\oint \mathbf{E} \cdot d\mathbf{l} = -\frac{\partial \Phi_B}{\partial t}$	Faraday's law of induction
$\nabla \times \mathbf{B} = \mu_0\epsilon_0 \frac{\partial \mathbf{E}}{\partial t} + \mu_0\mathbf{J}$	$\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0\epsilon_0 \frac{\partial \Phi_E}{\partial t} + \mu_0 i$	Ampere's law (extended)
$\nabla \cdot \mathbf{J} = -\frac{\partial \rho}{\partial t}$	$\oint \mathbf{J} \cdot d\mathbf{S} = -\frac{\partial q}{\partial t}$	Continuity equation

Instead, there is an Easy Way…

- First, let's build some insight.
  - Analogy

$F = m \cdot a$

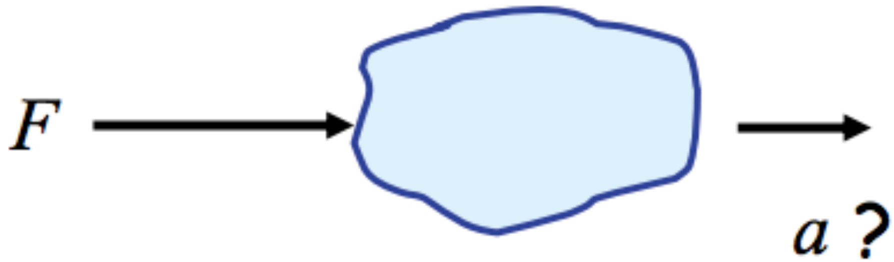


  - I ask you: what is the acceleration?
  - You may quickly ask me: what is the mass?
  - I tell you: m
  - You respond: $a = \frac{F}{m}$

Done!

  - Force abstraction.

Instead, there is an Easy Way…

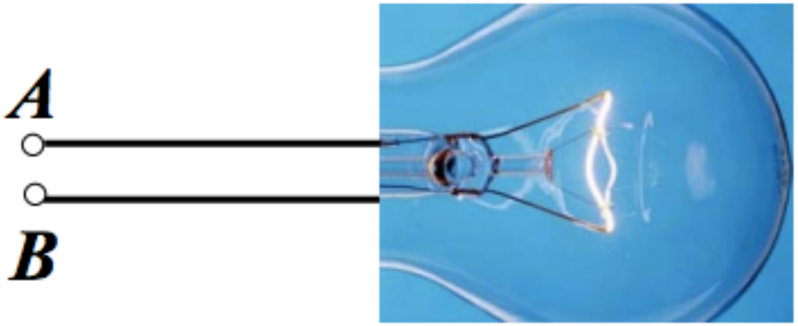


- In doing so, you ignored:
  - The object's shape
  - Its temperature
  - Its color
  - Point of force application
  - …

→ Discretization (lumping)

The Easy Way

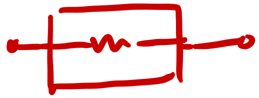
- Consider the filament of the light bulb.



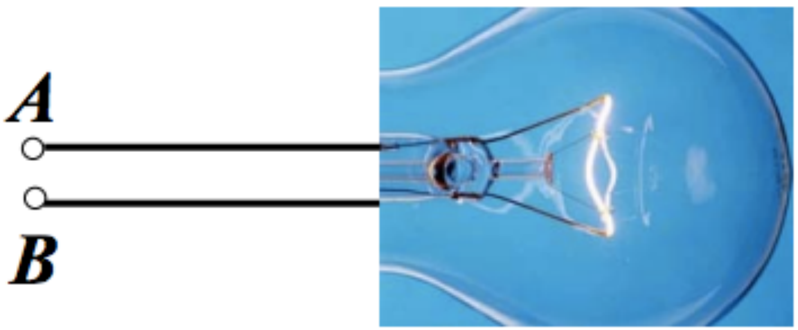
- We do not care about
  - How current flows inside the filament.
  - It's temperature, shape, orientation, …
- We can replace the bulb with a resistor
  - For the purpose of calculating the current.

The Easy Way

- We replace a bulb with a discrete resistor.

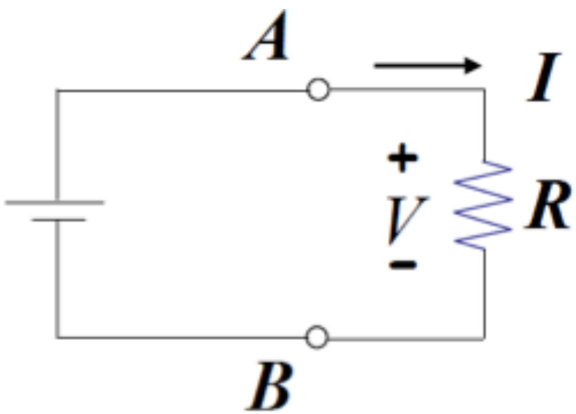


black box with 2 terminals.



- We engineers do things the easy way.
  - R represents the only property of interest!

V-I Relationship



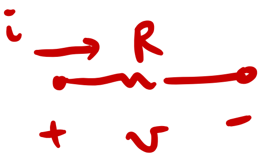
- R relates element V and I. $I = \frac{V}{R}$

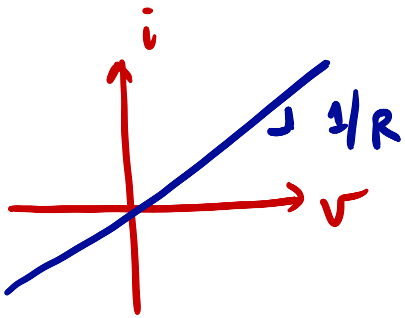
- R is a lumped element abstraction for the bulb.

Lumped Element

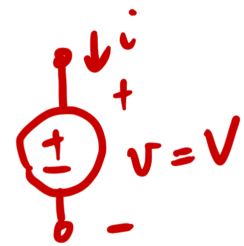
- Lumped circuit element is described by its v-I relation.

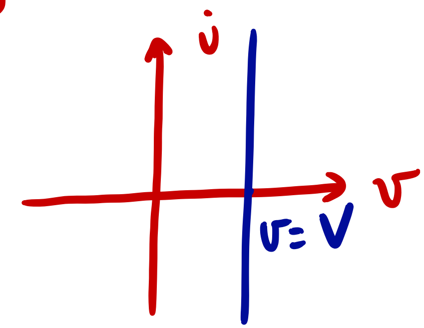
1) Resistor





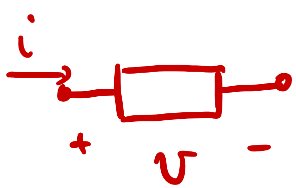
2) ideal voltage source





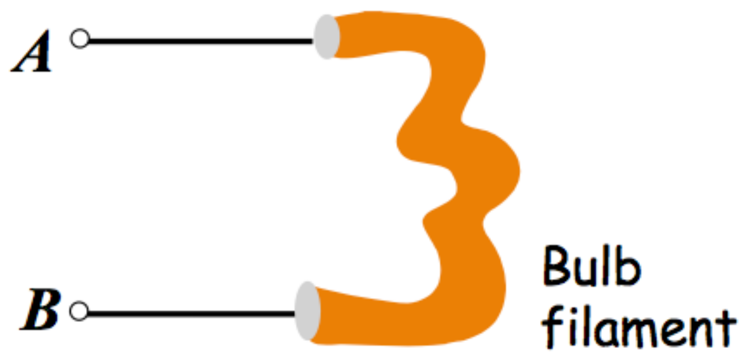
- Power is the time rate of expending or absorbing energy.
  - Power consumed by element

$$P = \frac{dE}{dt} = v \cdot i$$



Is R a lumped element abstraction for a bulb?

- Although we will take the easy way of using lumped abstraction for the rest of this course, we must make sure (at least for the first time) that our abstraction is reasonable.

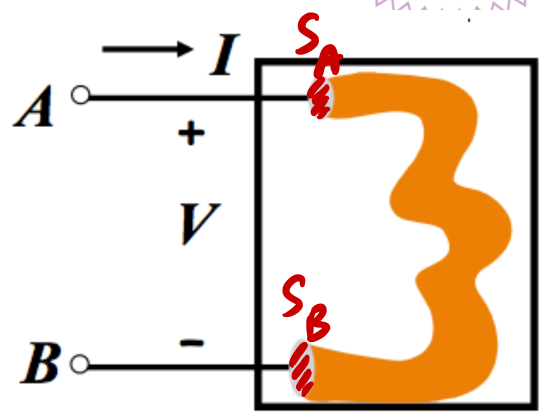


- In this case, ensure that V and I are defined for the element.

Current I must be defined

✓ I into S_A = I out of S_B

True only when $\int_{S_A} \vec{J}\cdot d\vec{s} - \int_{S_B} \vec{J}\cdot d\vec{s} = \frac{\partial q}{\partial t} = 0$



black box

- From Maxwell's equation

$$\oint_S J \cdot \mathrm{d}s = \oint_V \left(-\frac{\partial \rho}{\partial t}\right) \cdot \mathrm{d}v$$

$$-\int_{S_A} J \cdot \mathrm{d}s + \int_{S_B} J \cdot \mathrm{d}s = \oint_V \left(-\frac{\partial \rho}{\partial t}\right) \cdot \mathrm{d}v$$

$$I_A - I_B = \frac{\partial q}{\partial t}$$

$$I_A = I_B \quad \text{only if} \quad \frac{\partial q}{\partial t} = 0$$

Voltage V must be defined

- V is uniquely defined only when

$\frac{\partial \phi}{\partial t} = 0$ for any closed loop outside the element.

ϕ: magnetic flux

$\Rightarrow V_{AB} = \int_A^B E \cdot dl$

- From Maxwell's equations

$$\oint_C E \cdot \mathrm{d}l = \int_S \left(-\frac{\partial B}{\partial t}\right) \cdot \mathrm{d}s$$

$$V_{AB} - \int_A^B E \cdot \mathrm{d}l = \frac{\partial \phi_B}{\partial t}$$

$$V_{AB} = \int_A^B E \cdot \mathrm{d}l \text{ only if } \frac{\partial \phi_B}{\partial t} = 0$$

- The signal speed of interest should be way lower than speed of light.

Lumped Matter Discipline (LMD)

- Self imposed constraints:
  1. - Choose lumped element boundaries so that the rate of change of magnetic flux linked with any portion of the circuit must be zero for all time.

       $\frac{\partial \phi}{\partial t} = 0$ through any closed path outside the element
     - Choose lumped element boundaries so that there is no total time varying charge within the element for al time.

       $\frac{\partial q}{\partial t} = 0$ where q is the total charge inside the element
     - Operate in the regime in which signal timescales of interest are much larger than propagation delay of electromagnetic waves across the lumped elements.

So, what does LMD buy us?

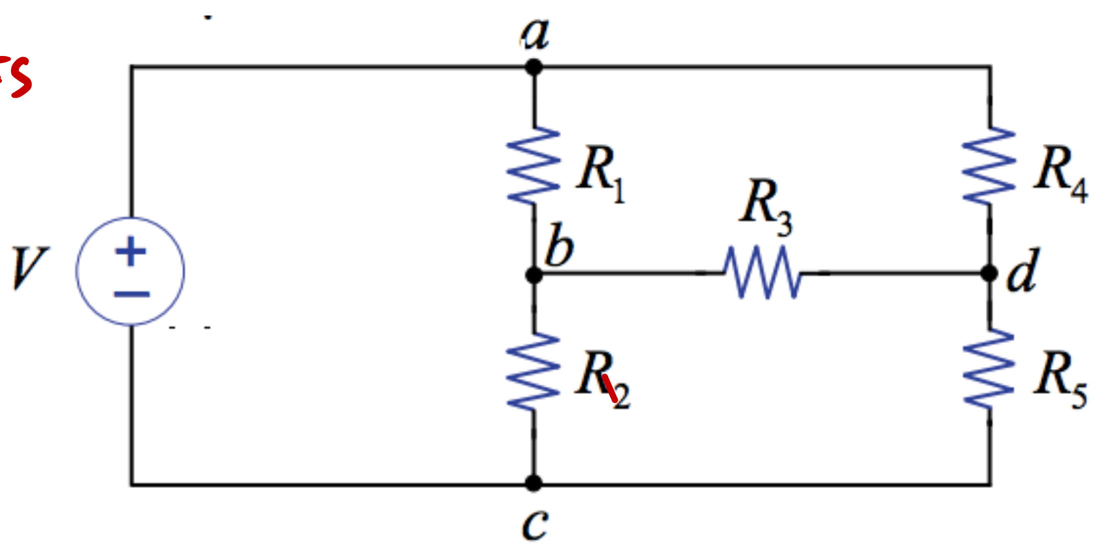
- Replace the differential equations with simple algebra using lumped circuit abstraction (LCA).
- For example

6 elements

4 nodes

6 branches

7 loops



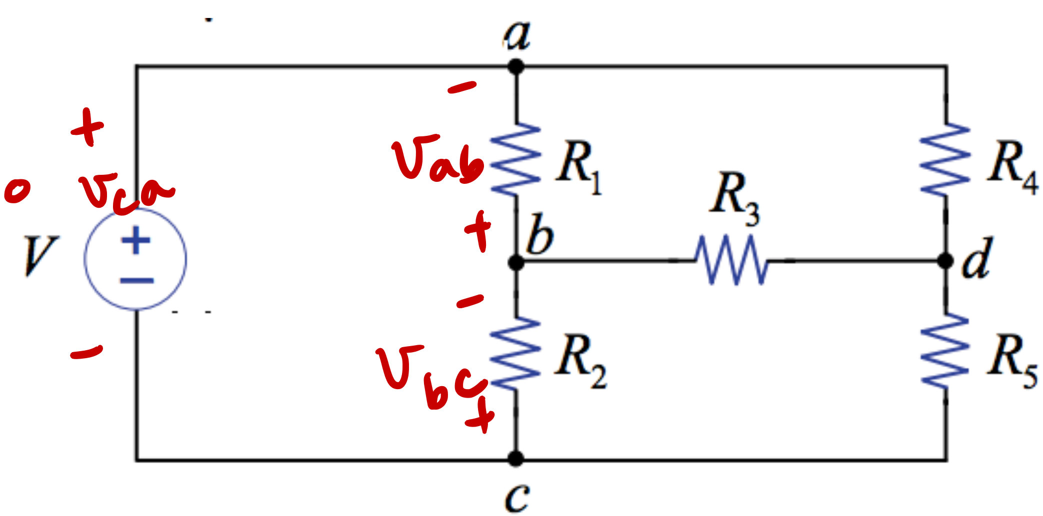
- What can we say about voltages in a loop under the lumped matter discipline?

What can we say about voltages in a loop under LMD?

$$\oint_C E \cdot \mathrm{d}l = -\frac{\partial \phi_B}{\partial t} = 0 \quad (\#1)$$

$$\int_c^a E\,dl + \int_a^b E\,dl + \int_b^c E\,dl = 0$$

$$\Rightarrow v_{ca} + v_{ab} + v_{bc} = 0$$



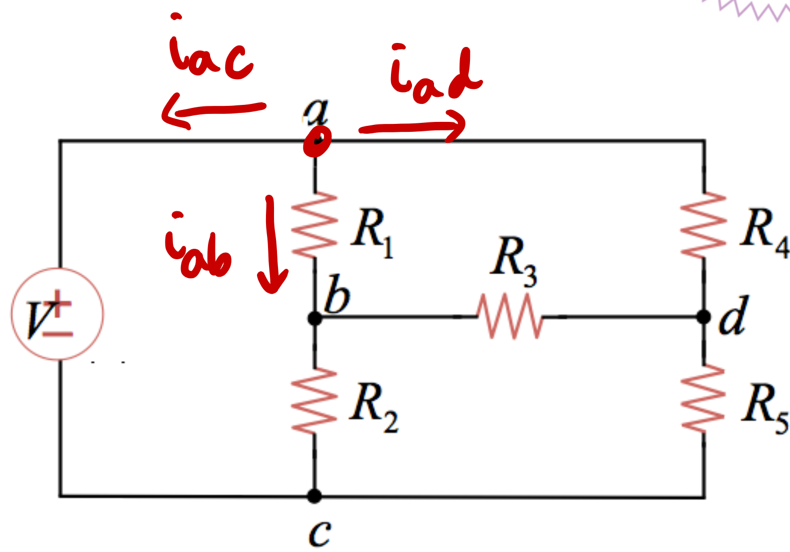
- Kirchhoff's Voltage Law (KVL):

  The sum of the voltages in a loop is 0.

What can we say about currents at a node under LMD?

$$\oint_S J \cdot ds = -\frac{\partial q}{\partial t} = 0 \ (\#2)$$

$i_{ac} + i_{ab} + i_{ad} = 0$



- **Kirchhoff's Current Law (KCL):**
  The sum of the currents into a node is 0
  - This is simply the conservation of charges.

KVL and KCL Summary

- Kirchhoff's Voltage Law (KVL):

$$\sum_{\substack{k \\ \text{loop}}} v_k = 0$$

- Kirchhoff's Current Law (KCL):

$$\sum_{\substack{j \\ \text{node}}} i_j = 0$$

Summary

- Lumped Matter Discipline (LMD)

$$\frac{\partial \phi_B}{\partial t} = 0 \quad \text{outside elements}$$

$$\frac{\partial q}{\partial t} = 0 \quad \text{inside elements}$$

  - Also, signal speeds of interest should be way lower than speed of light.

- Lumped circuit abstraction
  - Element described by its v-i relation.
  - Power consumed by element is v*i.

- Maxwell's equations simplify to algebraic KVL & KCL under LMD
  - Kirchhoff's Voltage Law (KVL): $\sum_j v_j = 0$ for loop
  - Kirchhoff's Current Law (KCL): $\sum_j i_j = 0$ for node