Lecture 1: Capacitors, RC Circuits
Course Information

- Course website: [https://inst.eecs.berkeley.edu/~ee16b/fa23/](https://inst.eecs.berkeley.edu/~ee16b/fa23/)
- Syllabus: [https://inst.eecs.berkeley.edu/~ee16b/fa23/policies.html#courseInfo](https://inst.eecs.berkeley.edu/~ee16b/fa23/policies.html#courseInfo)
- Instructors:
  - Ming Wu
  - Shyam Parekh
  - JP Tennant
- Course Staff:
  - 26 UCSs
Course Content

• Fundamentals of designing and building modern information devices and systems that interface with the real world

• Basic concepts covered in this course:
  – Circuits
  – Signals and systems
  – Basic control
  – Math skills

• Lab is an important component of the course
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Questions about Class

• General questions: use Ed Discussion: https://edstem.org/

• Personal questions:
  – Post privately
  – Email eecs16b-fa23@berkeley.edu
Reading Material

• Useful textbook for the first 10 lectures:
• Notes on the course website
• 105 reader chapters 1 and 2 are useful reference for this course (read it in the end or as we go along)
• Useful references for 16A (and general) circuit concepts:
EE 16A Assumptions

- Voltage, Charge, Current
- Energy, Power
- Resistors, Voltage / Current Sources
- KCL/KVL, Nodal Equations
- Voltage/Current Dividers
- Linearity, Superposition
- Norton/Thevenin Equivalents (Source Transformations)
- Loads / Source Resistance
Capacitance

• Capacitance is the capacity to store charge (and therefore energy)
• Unit: Farad, symbol: F
  – Named after English physicist Michael Faraday (1791-1867)
  – 1 F is an extremely large capacitance
  – Circuit components are typically in the range of μF or nF
  – Parasitic capacitances in semiconductor devices (e.g., transistors) are on the order of pF
Capacitors
Intentional Capacitors

- Capacitors act like tiny “batteries” that deliver current faster than actual supply
- Essential component in modern electronics
Unintentional Capacitors
Capacitor vs Battery vs Steak

- **Capacitor for EV**
  - 580 uF, 450V max voltage, 1 kg weight
  - 59 J
- **Tesla 3rd generation battery**
  - 333 Wh/kg = 1.1 MJ
- **Beef Steak, 1kg**
  - 10.5 MJ
Capacitors

- Two conductors (usually metal) separated by an insulator
- A capacitor stores charges \( q \)
- The charge is proportional to the voltage \( v \) across the metal plates:

\[
q = Cv
\]

Unit: Farad (coulomb/volt)
Current flow through a Capacitor

- **Remember**: Electrons flow in the opposite direction of current flow.
- If a current is flowing to the upper plate, electrons leave that plate resulting in a net positive charge on the upper plate, negative charges on the lower plate.
- An electric field is developed between the metal plates.
Current flow in a Capacitor

Current flow through a capacitor is proportional to the rate of change in potential difference of the plates

\[ i = \frac{dq}{dt} = C \frac{dv}{dt} \]

Time Varying Voltage

\[ v(t) = \frac{1}{C} \int_{t_0}^{t} i(t) \, dt + v(t_0) \]

Time Varying Charge

\[ q(t) = \int_{t_0}^{t} i(t) \, dt + q(t_0) \]
Stored Energy in a Capacitor

- Capacitors store energy in the electric field
- Power \( p \) delivered to a circuit element is the product of the current and the voltage.
  \[ p(t) = v(t)i(t) \]
- Energy \( w \) is the power integrated over time.
  \[ p(t) = v(t) \frac{Cd\nu(t)}{dt} = C \frac{v(t)d\nu(t)}{dt} \]
  \[ p(t)dt = Cv(t)d\nu(t) \]
  \[ w = C \int_{0}^{V} v dv = \frac{CV^2}{2} \]
Voltage, Current and Energy in a Capacitor

\[ v(t) \]

\[ i(t) \]

\[ p(t) \]

\[ w(t) \]
Series and Parallel Capacitors

**Series:**

\[ i = C_{eq} \frac{dv}{dt} = C_{eq} \frac{dv_1}{dt} + C_{eq} \frac{dv_2}{dt} \]

\[ \frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} \]

\[ v(t) = v_1(t) + v_2(t) \]

**Parallel:**

\[ i = i_1 + i_2 + i_3 = C_1 \frac{dv}{dt} + C_2 \frac{dv}{dt} + C_3 \frac{dv}{dt} \]

\[ C_{eq} = C_1 + C_2 + C_3 \]
Physics of Capacitors

• Gauss’s Law

\[ \iiint_S E \cdot dA = \frac{q}{\varepsilon_0} \]

• Parallel plate capacitor
Role of Dielectric

Diagram showing plate mobile charges and induced fixed charges with net induced charge equal to zero (cancellation).