# EE40
# Lecture 7
# Josh Hug

7/7/2010

# Blackboard Stuff

- HW3 concerns
- Any general questions people might have

# General Info

- No lab today
- Midterm on Friday in class
  - **12:10-1:30  [be on time!]**
  - No electronic devices
  - One 8.5”x11” (or A4) sheet of paper
    - Handwritten anything you want, both sides
- HW4 due next Friday (will be posted Friday)
- No positive feedback circuits on the midterm (but there might be on the final)

# Project 2

- Project 2 spec to be posted over the weekend
- If you'd like to do something other than the official project, you can submit a specification for your Project 2:
  - Team members (up to 3)
  - Parts list
  - Schematic
- Must have substantial hardware component
  - Microcontrollers are OK, but your project shouldn't be about assembly programming
  - MyDAQ is also OK, but your project shouldn't be about LabVIEW programming
- Custom project proposals due WEDNESDAY by 5 PM

# Guest Mini-Lecture Today

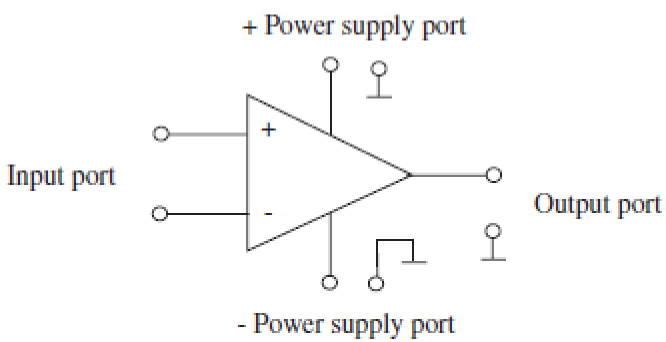
- Jeff Jansen from National Instruments will be talking today for the last half hour
  - MyDAQ data acquisition device
    - USB device that lets you use your computer in lieu of big bulky specialized test equipment
  - Can use this device to do labs from home or anywhere else a laptop functions
  - If anyone wants to use these in labs, we will have 10 of them available
  - Could be handy for Project 2
    - Must have substantial hardware component (can't just be LabVIEW software written for MyDAQ)

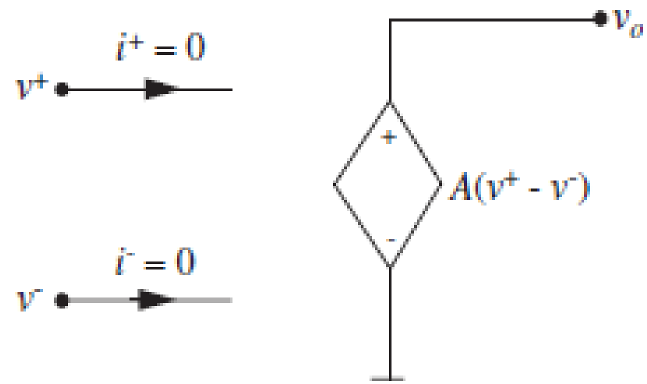
# Course Website

- I am assured that the rest of the calendar and the other 5 labs will be posted shortly. Most likely schedule is:
  - 7/13: Project 1 (buzzer)
  - 7/14: Sound synthesizer
  - 7/20: Power supply
  - 7/21: Active filter lab
  - 7/27-8/11: Project 2
- Future reading assignments will be posted 3 days before they're due
  - Micro-deadlines are needed for me, too!

# Op-Amp Saturation

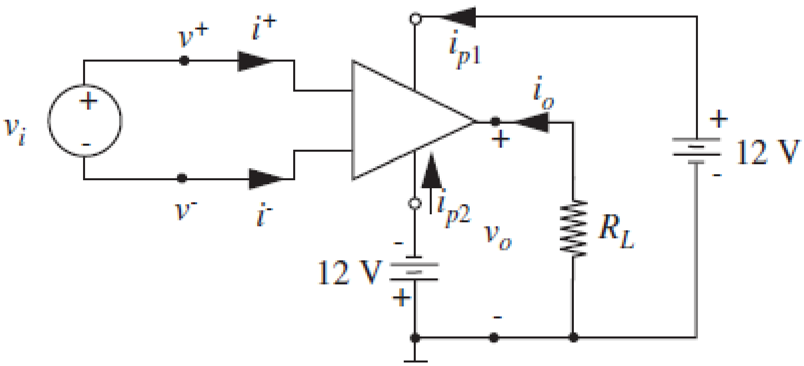
- Remember those power ports we've been ignoring?

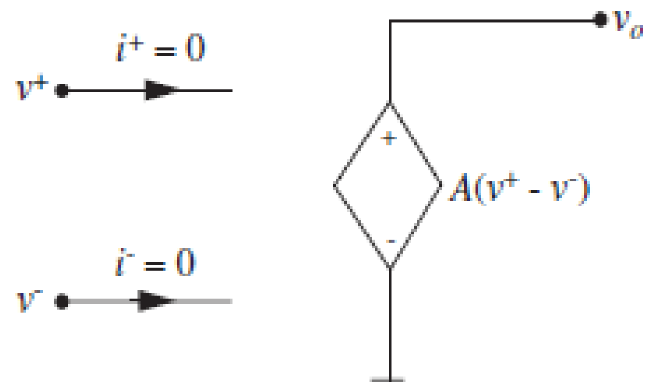



- They specify the maximum and minimum voltage that our op-amp can deliver
  - If $v_{min} < A(v^+ - v^-) < v_{max}$
    - Op-Amp output is $A(v^+ - v^-)$
  - If $A > v_{max}$,
    - Op-Amp output is $v_{max}$
  - If $A < v_{min}$,
    - Op-Amp output is $v_{min}$

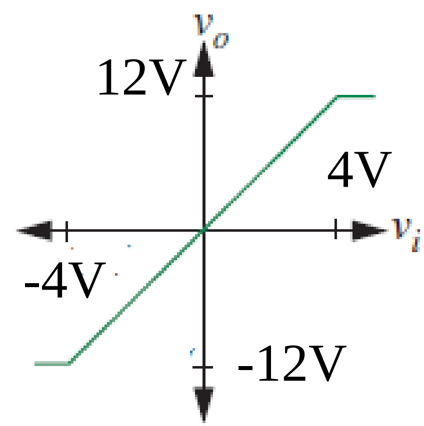
# Op-Amp Saturation Example



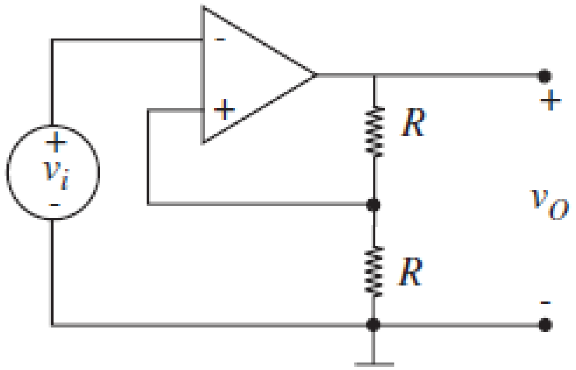




- $v_{max} = 12V, v_{min} = -12V$
- If A=3:

| $V_{in}$ | $V_o$ |
|---|---|
| -5 V | -12V |
| -1V | -3V |
| 2V | 6V |
| 1,512,312V | 12V |



# Positive Feedback



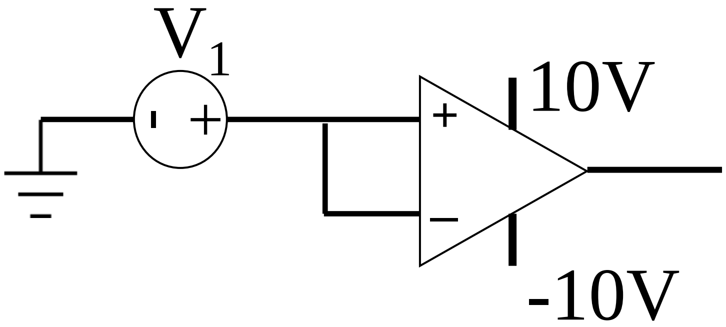

On the board

# Another Op-Amp Model Revision

- Real amplifiers deviate from the ideal
  - Input resistance between $V^+$ and $V^-$
  - Output resistance at the output of the dependent source

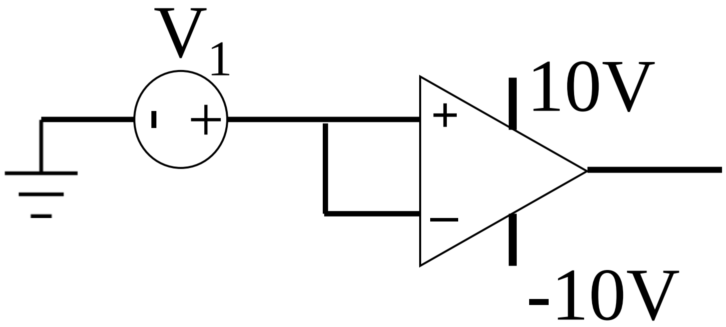
- Another significant problem is “common mode signal amplification”

# Common Mode Signal




- In theory, the above amplifier would have an output voltage of **0V**
- In practice, even an equal signal will leak through a little
- $V_{out} = A_d(V^+ - V^-) + \underbrace{\frac{A_c(V^+ + V^-)}{2}}_{\text{New Term}}$

# Common Mode Signal




- $V_{out} = A_d(V^+ - V^-) + \frac{A_c(V^+ + V^-)}{2}$
- $A_d$ and $A_c$ are typically not explicitly considered
- Instead, we consider the "Common Mode Rejection Ratio" $CMRR = \frac{A_d}{A_c}$
- Big is good, less common mode signal

# Example of using CMRR

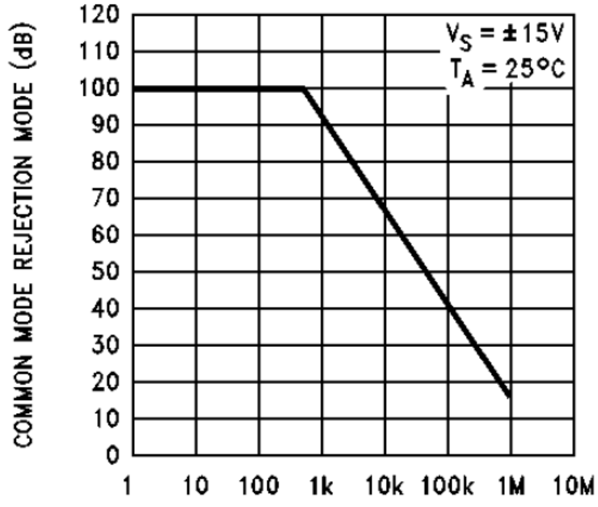
- Find $V_o$ as a function of $R_s, \mathrm{R_f}, \mathrm{CMRR}$

- (On board)

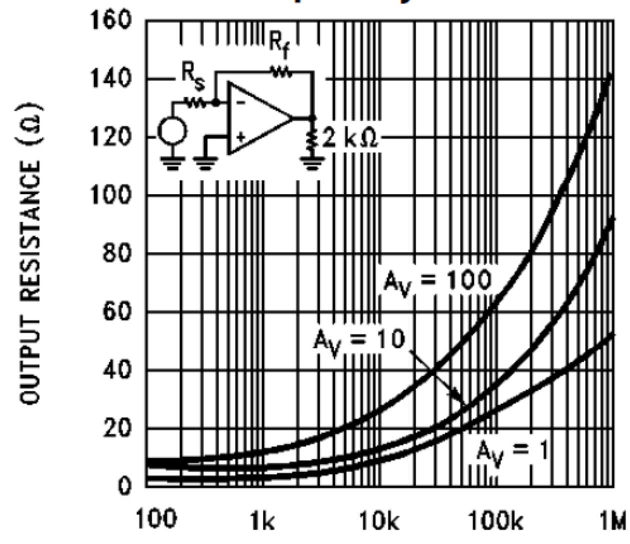
# One of many Op-Amp parameters

- Typical CMRR is 35,000 (~90 dB)
  - Usually measured in db
    - $CMRR_{db} = 20 * \log_{10}(CMRR)$
- In real life, Op-Amps come with multipage data sheets (as do everything else)

**Common Mode Rejection Ratio vs Frequency**




**Output Resistance vs Frequency**



# How are you feeling about…

- How are you feeling about Node Voltage and solving basic circuits?
  - A. Completely lost
  - B. A little behind
  - C. Alright
  - D. Pretty good
  - E. Feel like I’ve attained mastery

# How are you feeling about…

- How are you feeling about I-V characteristics and Thevenin and Norton equivalents?
  - A. Completely lost
  - B. A little behind
  - C. Alright
  - D. Pretty good
  - E. Feel like I've attained mastery

# How are you feeling about…

- How are you feeling about Op-Amp circuits?
  - A. Completely lost
  - B. A little behind
  - C. Alright
  - D. Pretty good
  - E. Feel like I’ve attained mastery

# How are you feeling about…

- How are you feeling about the midterm?
  - A. Terrified
  - B. A little scared
  - C. Neutralish
  - D. Feel prepared
  - E. Feel like I will do excellently

# Make up Labs

- Do you need a make up lab?
- A. Yes
- B. No

- This is where we stopped

# UNIT 2

## Elements with Memory
## a.k.a. Energy Storage Elements

# Preview of Unit 2

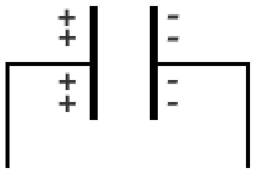
- In the next major unit of the class, starting next Monday, we'll be discussing elements with memory
  - Capacitor: Gives relationship between $I$ and $\frac{dv}{dt}$
  - Inductor: Gives relationship between $V$ and $\frac{di}{dt}$
- Fundamental mathematical difference is that their $IV$ relationship changes with time
- Fundamental physical difference is that they can store energy
- For the rest of today, we'll give a sneak preview of this material

# RC Circuits

- Taking the Live Demo risk, let's check out a quick qualitative circuit simulation

# The Capacitor

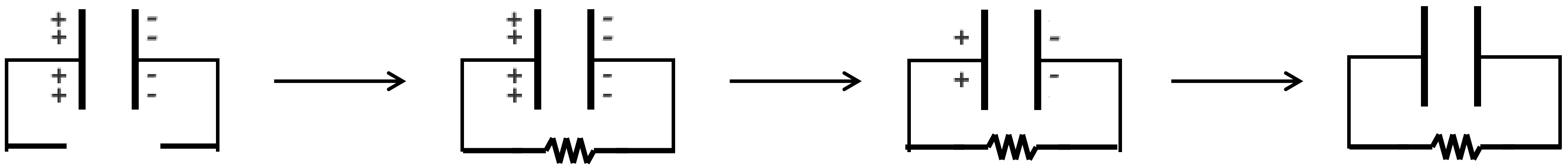
- The basic idea is pretty simple
  - Imagine you have two parallel metal plates, both of which have equal and opposite excess charges
  - Plates are separated by an insulating layer (air, glass, wood, etc)




- The charges would love to balance out
- Insulator blocks them (just as the ground blocks you from falling into the center of the earth)

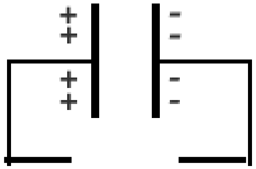
# The Capacitor

- If you were to connect a resistive wire to the plates
  - Charges would flow through the wire
    - Charge flow is current
    - $P = I^2R$
    - Energy has been released as heat



# The Capacitor

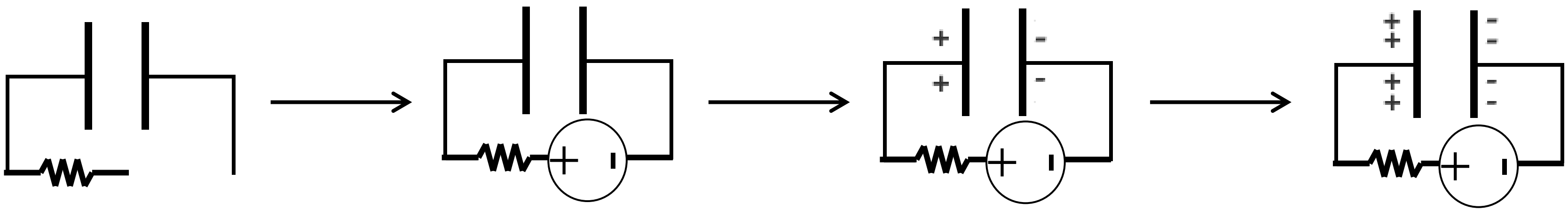
- Remember that a voltage is the electrical potential between two points in space




- Here, we have an imbalance of charge, and thus an electric field, and thus a voltage $V = EL$
  - Field strength is dependent on number and distribution of charges as well as material properties
  - Field length is dependent on size of capacitor
  - Capacitor size and material properties lumped into single "capacitance" C
    - $V = QC$

# The Capacitor

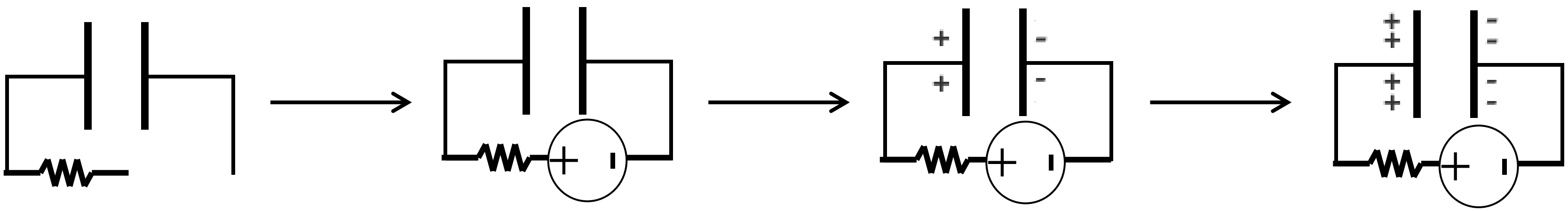
- Thus, if you connect a voltage source to the plates
  - Like charges will move to get away from the source
    - Charge flow is current
    - Current will stop once charges reach equilibrium with voltage source, i.e. $V_c = V_s$
    - Energy has been stored



# The Capacitor

Lots of current

Zero current



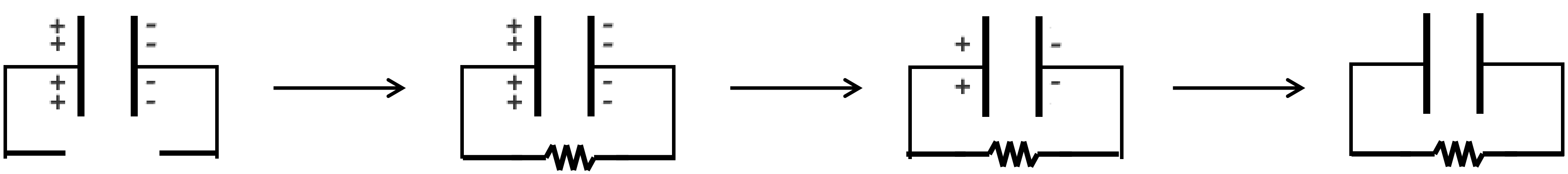
Zero $V_C$

$V_C = V_S$

$$I = C\frac{dV}{dt}$$

Lots of current

Zero of current

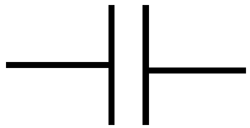


High $V_C$

Zero $V_C$

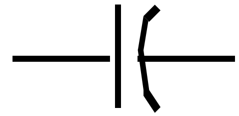
# Capacitor

**Symbol:**

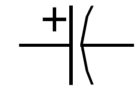


*C*

or



*C*




*C*

**Electrolytic (polarized) capacitor**

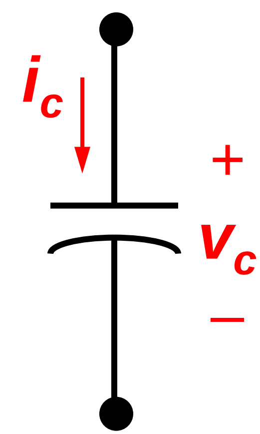
These have high capacitance and cannot support voltage drops of the wrong polarity

**Units:** **Farads (Coulombs/Volt)**

**(typical range of values: 1 pF to 1 μF; for "supercapa-citors" up to a few F!)**

**Current-Voltage relationship:**

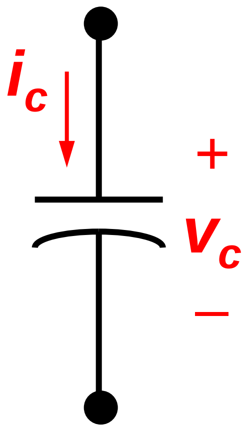
$$i_c = \frac{dQ}{dt} = C\frac{dv_c}{dt}$$




**Note:** $v_c$ **must be a continuous function of time since the charge stored on each plate cannot change suddenly**

# Node Voltage with Capacitors

$$i_c = \frac{dQ}{dt} = C\frac{dv_c}{dt}$$

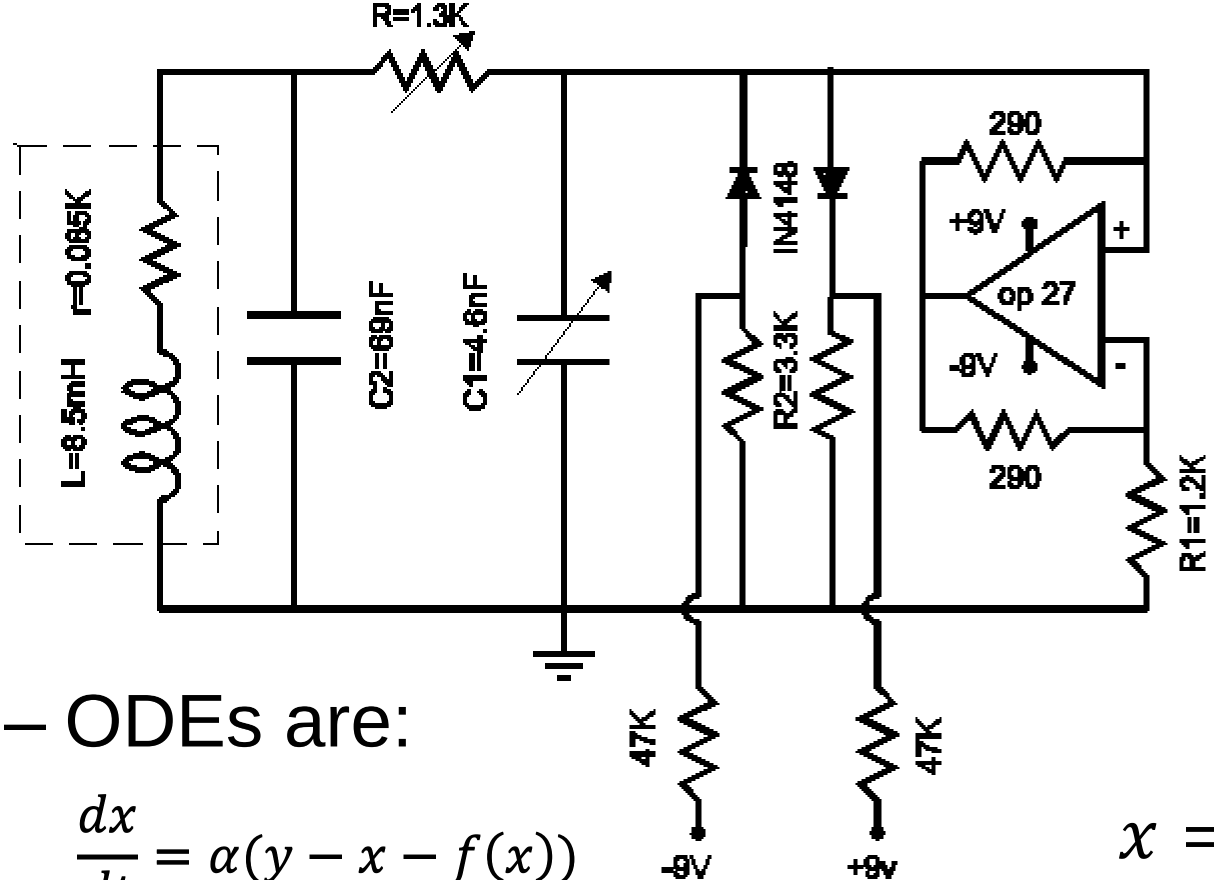



- On board

# Ordinary Differential Equations

- Inductors, too, give us a simple 1st order relationship between voltage and current
- Node Voltage with memoryless circuits gave us algebraic equations
- Node voltage with elements with memory will give us Ordinary Differential Equations (ODEs)
- Next week will be a bunch of setting up and solving 1st and 2nd order linear ODEs
- Higher order and especially nonlinear ODEs are tough to solve. For example…

# Chua's Circuit




$f(x)$ – response of diodes and resistor block

– ODEs are:

$$\frac{dx}{dt} = \alpha(y - x - f(x))$$

$$\frac{dy}{dt} = x - y + z$$

$$\frac{dz}{dt} = -\beta y$$

$$x = v_{C1}$$

$$y = v_{C1}$$

$$z = i_I$$

# Chua's Circuit

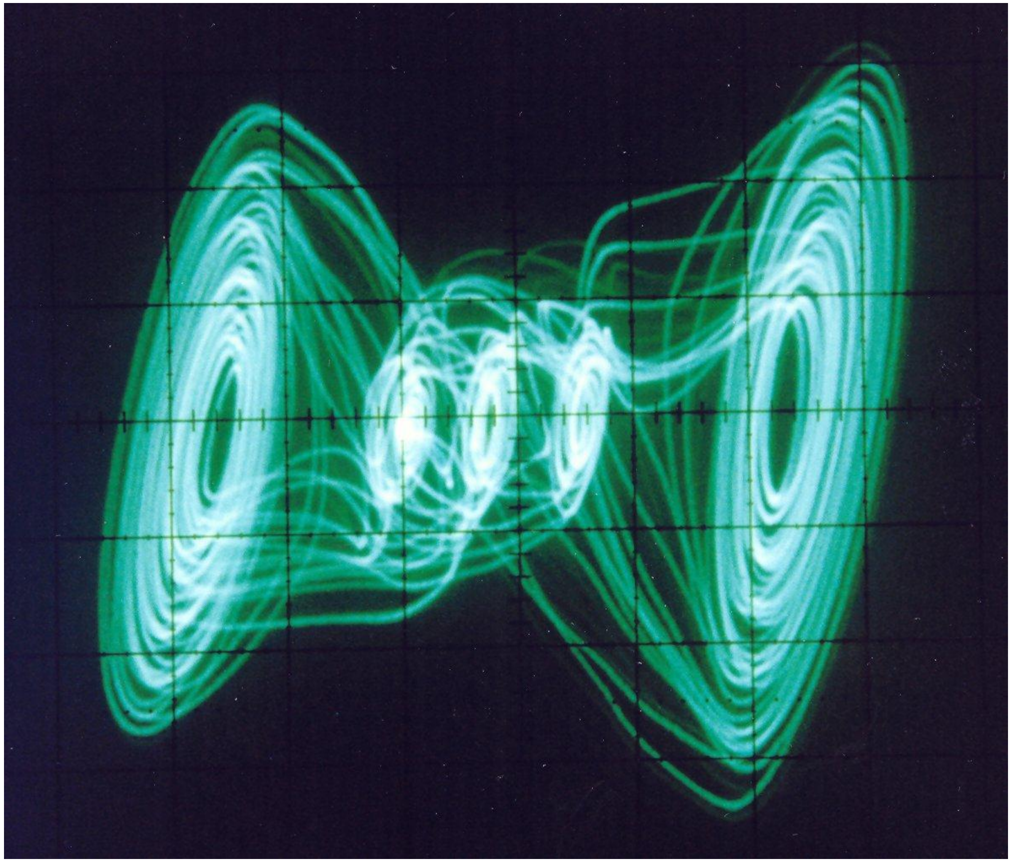
- Despite simplicity of ODEs

$$\frac{dx}{dt} = \alpha(y - x - f(x))$$

$$\frac{dy}{dt} = x - y + z$$

$$\frac{dz}{dt} = -\beta y$$

- Exhibits chaos!



Invented by current UC Berkeley EECS professor Leon Chua in 1983

# Capacitors

- Useful for
  - Storing Energy
  - Filtering
  - Modeling unwanted capacitive effects, particularly delay

# Good luck on your midterm!

- Now on to Jeff's presentation