University of California at Irvine
MAE106 Mechanical Systems Laboratory: Lecture 1

Part 1: Overview of the Class

If you work hard, you will leave this class with knowledge and practical experience in three interrelated areas:

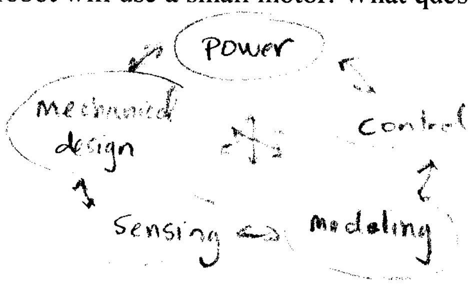
1. Physical intuition about how 1st and 2nd order linear, dynamical systems behave
   - You will be exposed to examples of common electrical, vibration, and robotic systems
   - Basic Idea: The dynamics of a wide variety of physical objects obey 1st and 2nd order linear, differential equations. These systems respond exponentially, sinusoidally, and exposoidally (OK, that's not a real word, but try to get the idea) in the time domain.
   - You will learn how to think about their behavior in both the time and frequency domains
2. Basic understanding of how feedback control works
   - Feedback is a common way to make cars, planes, robots, etc. respond like we want them too
   - You will learn about proportional feedback control (and derivative and integral control)
   - Basic idea: Measure error and try to reduce by changing the input to the controlled object
3. Familiarity with the components and tools for building mechatronic and robotic systems
   - Motors, potentiometers, tachometers, analog computational circuits (op-amps), electrical filters, power amplifiers, data acquisition systems, oscilloscopes, protoboards, ohmmeters

Part 2: Design Exercise

Final Project Competition: Build a robotic soccer player that can do two things:

1. kick a penalty kick
2. goal tend to block a penalty kick by another robot

Your robot will use a small motor. What questions do you need to know the answer to in order to build this robot?



Part 3: Review of Circuit Theory

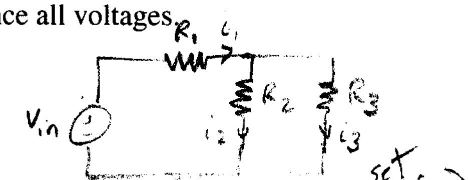
3.1 Linear circuit elements

Current: think of it as the flow of charge through a circuit element (such as a wire or resistor) Units: amps=coulombs/sec

Voltage: think of it as the electrical pressure that can cause charge carriers to flow

Current is always measured through something at a point; voltage is always measured between two points

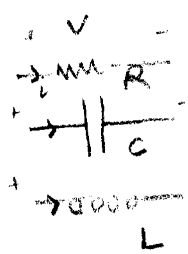
For this class, "ground" is an arbitrarily defined point on a circuit to which we reference all voltages



Toolbox for circuit analysis

- Kirchoff's Current Law: $\sum$ current in = $\sum$ current out
- Kirchoff's Voltage Law: $\sum_{loop}$ Voltage = 0 $\quad -V_{in} + V_1 + V_2 = 0$
- Power $P = Vi$ (stored or dissipated)
- Triad of linear circuit elements:

	i	$\frac{di}{dt}$
V	R	L
$\frac{dv}{dt}$	C	"Flux Capacitor"



$V = L\frac{di}{dt}$

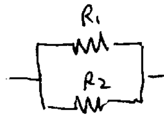
ohms (= 1/siemens) (set gains & voltages)

farads (filters)

henrys (motors, used to ignite spark plug in automobile engine)

Resistor Analysis Exercise:
Abstraction: the act of considering something as a general quality or characteristic apart from any concrete realities, specific object, or actual instance. It's the idea of a "black box"

ABSTRACTION, PATTERN RECOGNITION, + CIRCUIT ANALYSIS



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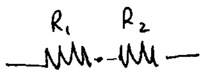
$$R_{eq} = \frac{R_1 R_2}{R_1 + R_2}$$

ALSO

V = IR

KCL

KVL



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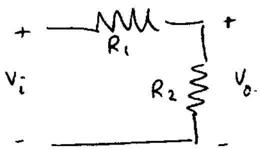
$$R_{eq} = R_1 + R_2$$



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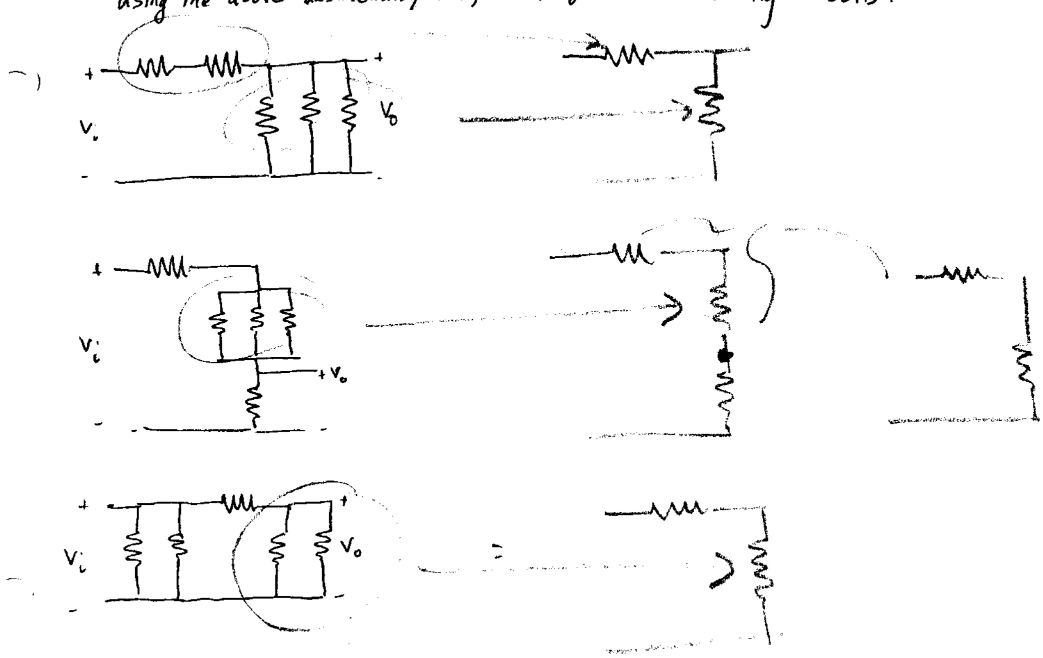
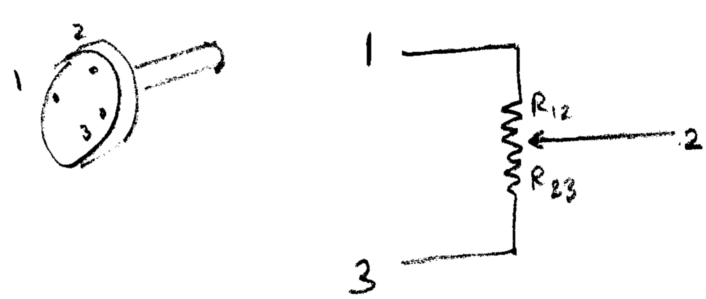
$$V_o = \frac{R_2}{R_1 + R_2} V_i$$

Using the above abstractions/rules, find V_o for the following circuits:



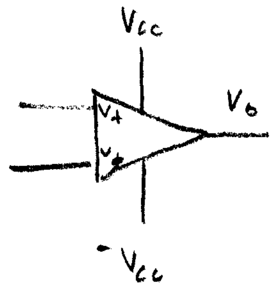
Potentiometers:
Typically used as voltage dividers. The two resistor values are changed by turning the pot.



$R = R_{12} + R_{23} =$ [50kΩ, for example]

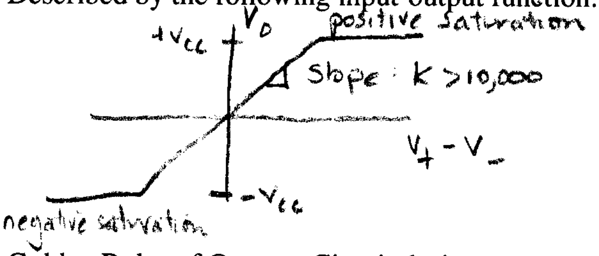
$$V_{out} = \frac{R_{23}}{R} V_{in}$$

3.2 Operational Amplifiers



- important building blocks for circuits; easy to use, cheap
- used to build filters, amplifiers, feedback controllers, computational circuits
- the "brains" in the analog control circuits that you will build for the class
- What are they? High gain, differential, linear voltage amplifiers
- Made of > 20 transistors plus resistors and capacitors
- Two input terminals, one output, two power supply lines (five pins total)
- Typically operate over a wide range of supply voltages
- By design, they have a high input resistance and a low output resistance

Described by the following input-output function:



in linear region

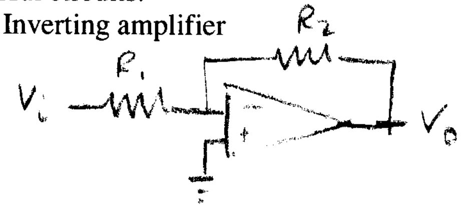
$V_o = K(V_+ - V_-)$

Golden Rules of Op-amp Circuit design:

1. Input currents are zero (op amps are designed to have a high input resistance)
2. Input voltages are equal (If operating in linear region, and connected with negative feedback)

Four useful circuits:

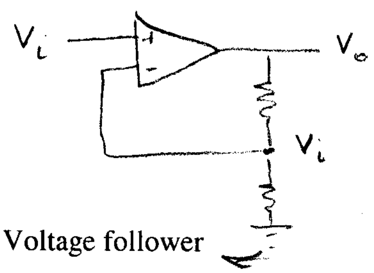
1. Inverting amplifier



What is V_o as a function of V_i?

KCL: $\frac{V_i}{R_1} + \frac{V_o}{R_2} = 0$ $\quad V_o = -\frac{R_2}{R_1} V_i$

2. Non-inverting amplifier

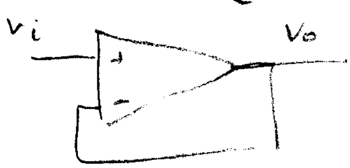


$\frac{V_o - V_i}{R_1} = \frac{V_i}{R_2} \Rightarrow V_o = \frac{R_1}{R_2} V_i + V_i$

$V_o = \left(\frac{R_1 + R_2}{R_2} \right) V_i$

as $R_2 \to \infty$ what does this circuit do?

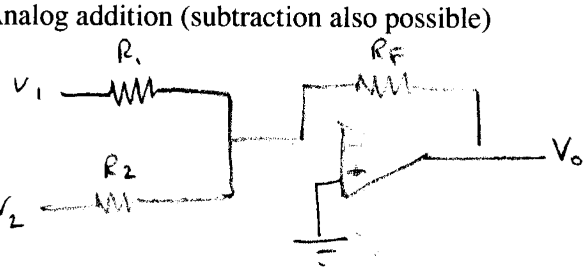
3. Voltage follower



$V_o = V_i$

why? - high input impedance lets us connect circuit modules without altering their performance

4. Analog addition (subtraction also possible)



$\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_o}{R_F} = 0$

$V_o = -R_F \left(\frac{1}{R_1} V_1 + \frac{1}{R_2} V_2 \right)$

If $R_1 = R_2 = R$

$V_o = \frac{-R_F}{R} (V_1 + V_2)$

Note: feedback is always to V_- (negative feedback)

$|V_o| < |V_{cc}|$ and $i_{out} < i_{max}$ else op-amp saturates

3.3 Controlling power needed for devices like motors, light bulbs, etc.

Often we want to control a device that requires a lot of power (e.g. a motor) with signals that have very low power (e.g. an op amp or computer).

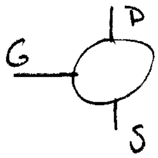
Small DC brushed motor: $V = 10\ V,\ R = 2\ \Omega \quad i = \frac{V}{R} = 5$ amps

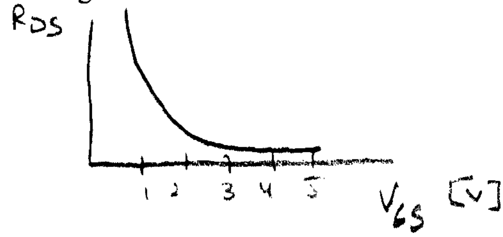
Typical Op-amp: $V = \pm 15\ V,\ i_{max} < 20$ mamp

Solutions?

1. Power op-amp
2. Power transistor (e.g power MOSFET – simple and cheap)

Can think of a MOSFET as a voltage controlled resistor that can take a lot of current





Notes: Input resistance is very high (therefore effectively no current goes into gate)

Low-power MOSFETS are the "switches" used in computers (what is a switch?)

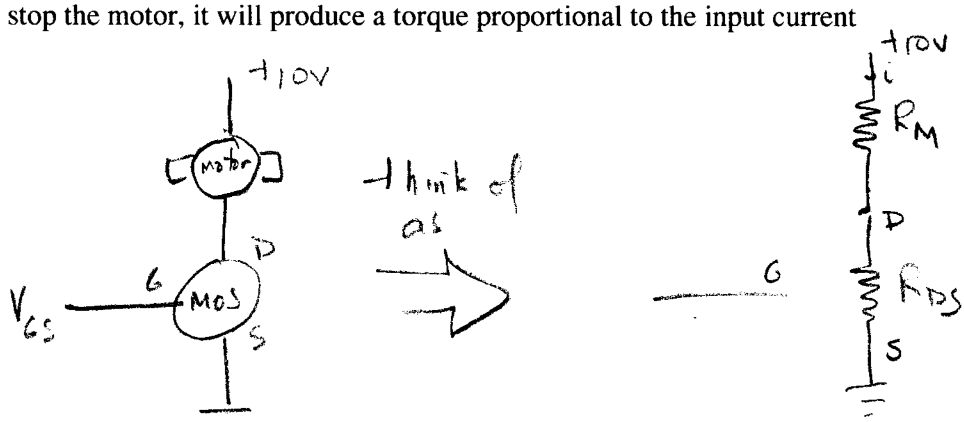
MOSFETS are very sensitive to static electricity – use a grounding strap when you handle them in lab

Example: use a power transistor to control a motor with a low-power computer output

Hints about motors:

A DC brushed motor spins at a speed proportional to the input voltage, if it is just turning an inertial load.

If you stop the motor, it will produce a torque proportional to the input current



If R_{DS} is big, no current flows

If R_{DS} is small (because V_{GS} is small) current flows

Thus, by controlling V_{GS}, we can make the motor turn or not turn

low power

no current