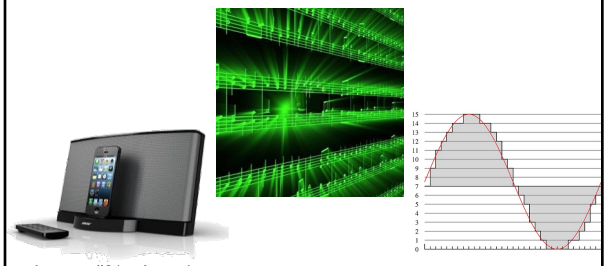
Penn Engineering ESE



Lecture #21 – Actuation

ESE 1500 – Digital Audio Basics

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Lecture Topics

- Where are we on course map?
- Review Sound
- Sensing
- Actuation
  - Motor
- Closing the loop (part 2)
  - Servo
  - Control
  - PWM

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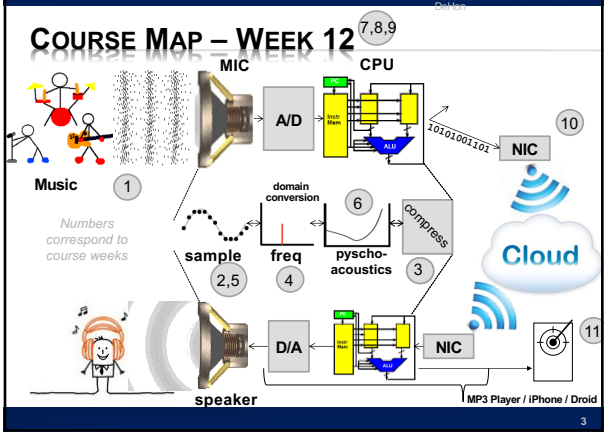
Course Map – Week 12



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Penn Engineering ESE

Review

4

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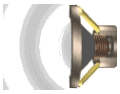
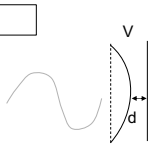
Week 1: Pressure to Voltage



- Microphones convert pressure to voltage
  - (speakers/headphones voltage to pressure)
  - Physical position to voltage

Δd → ΔC → ΔV

- Reason as parallel plate capacitor
  - ESE 1120 or PHYS 0151



$$C = \frac{\varepsilon A}{d}$$

$$Q = CV \qquad V = \frac{Q}{C}$$

Voltage is a function of distance (pressure)

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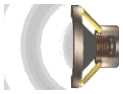
Speakers/Microphones



- Can sense the world
  - Physical effect (position)
  - Convert to voltage … to bits
- Can manipulate the world
  - Bits → voltage
  - Voltage causes physical movement

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SENSING

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SENSING

- What do we need to sense in the world?
- How might we sense?

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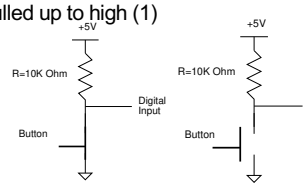
SWITCH

- **Can easily give a high or low input**
  - Connected short to ground (0)
  - Unconnected, weakly pulled up to high (1)



- **Read on input pin**
- **Use to sense position**
  - Did something make contact to actuate switch?
- **How use switch sensor for collision detection?**
  - Other uses?

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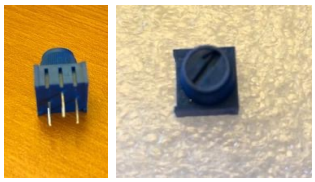
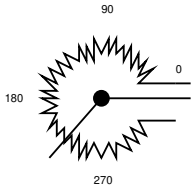
POTENTIOMETER

- **Variable Resistance**
  - Based on position, different amount of resistance across
  - $R = \rho L/A = R_0 * L$
  - $R \sim= R_0 * 2\pi r$ * (degrees/360)





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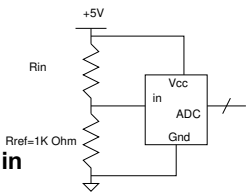
PRECLASS 1

- **Voltage at ADC Input**
  - Rin=10 Ohm ?
  - Rin=10K Ohm ?



- **V=I*R**
- **No current flows into ADC in**
- **I(Rin) = I(Rref)**
- **For Rin < Rref, where is most of voltage?**
- **For Rin > Rref, where is most of voltage?**

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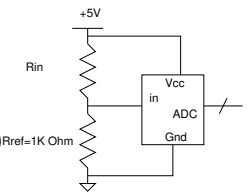
PRECLASS 1

- **V=I*R**
- **I=5V/(Rin+Rref)**
- **Vadc=I*Rref**
- **Vadc = 5(Rref / (Rin+Rref))**
- **Vadc = 5(1000 / (Rin+1000))**
- **Voltage at ADC Input**
  - Rin=10 Ohm ?
  - Rin=10K Ohm ?



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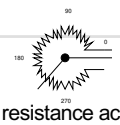
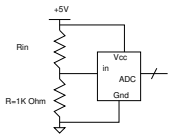
Sense Position



- **Variable Resistance**
  - Based on position, different amount of resistance across
- **Voltage Divider**
  - Output voltage depends on potentiometer position/resistance



- **Get analog voltage out**
- **Feed to A2D**
- **How useful for steering? revolutions?**
  - Other uses?

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Actuation

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Sensing

- **What do we need to control (actuate) in the world?**
- **How might we exert mechanical control?**

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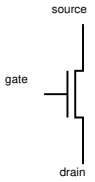
On-Off Switch

- **Logic produces a 0/1**
- **Can control flow of much larger current**
  - Stop flow – off
  - Enable flow – on
- **Transistors**
  - Voltage on input (gate) controls current flow (resistance) between source and drain



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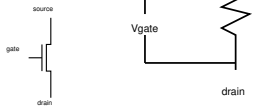
On-Off Switch

- **Logic produces 0/1**
- **Can control flow of much larger current**
  - Stop flow – off
  - Enable flow – on
- **Transistors**
  - Voltage on input (gate) controls current flow (resistance) between source and drain
  - Simplified model
    - Vgate>Vref – R=Rtrans
    - Vgate<Vref -- R=infinite



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On-Off Switch

- **Easy to produce 0/1**
- **Can control flow of much larger current**
  - Stop flow – off
  - Enable flow – on
- **Relay**
  - Similar model
    - Input voltage controls switch
  - Mechanical switching
  - Lower resistance
  - Different (usually larger) voltage range, current

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On-Off Powerful

- **Many things can control just by turning on or off**
  - How often on or off
  - When turn on or off
- **Examples control with On-Off?**
  - Temperature – when turn on heater (cooler)
  - Position – turning on or off motor

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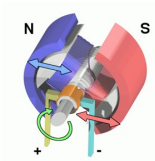
Motor – abstract view

- **Providing currents across a motor causes it to spin**
  - Magnitude of current determines how fast



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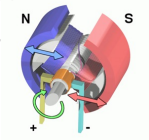
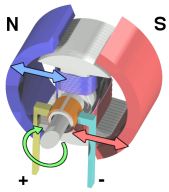
Motor



- **Exploits magnetic attraction/repulsion and electro-magnetic fields**
- **Run current through wire windings**
  - Induces electromagnet
  - Motor turn to line up with external magnets
- **Switch current direction**
  - Turns again to realign magnet
- **Continue to switch to cause continuous rotation**



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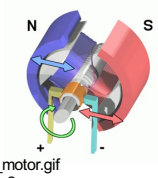
Motor Control

- **Control our motors with voltages and currents**
- **Control those with transistors/relays**
- **Controllable from our computers**



Pictures from:
https://en.wikipedia.org/wiki/Electric_motor#/media/File:Electric_motor.gif
https://commons.wikimedia.org/wiki/File:Electric_motor_cycle_2.png

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Part 2

Closing the Loop

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Control

- **Our mechanical (and electrical) components are often noisy**
  - E.g., non-linear, motor-specific relationship between current and speed or rotation
- **The physical world causes disturbances**
  - Obstacles
  - Tires or pulleys slip
  - Wind
- **How do we get reliable actuation when faced with variable behavior, noise, disturbances?**

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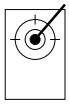
Servo – Basic Function

- Can specify a position (0 to 180 degrees)
- Will rotate shaft to position
- Where might we use?
  - Steering
  - Positioning
  - Pan/tilt



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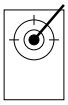
Servo – How Work

- Motor + sensor + control
- Sense if motor in position
  - If not, turn on motor in appropriate direction to move closer to position



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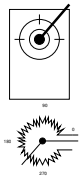
Servo - Control

- Motor moves shaft
- Sense position of shaft with potentiometer
- Use to decide if need to move



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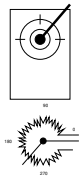
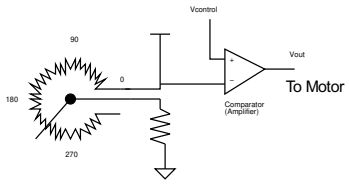
Servo - Control

- Move moves shaft
- Sense position of shaft with potentiometer
- Use to decide if need to move
- Compare with a reference





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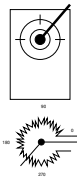
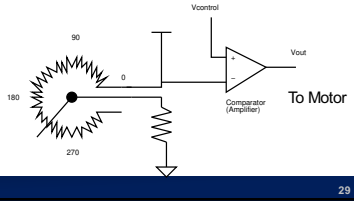
Servo - Control

- Compare with a reference
- Assume comparator computes: Vout=A*(V+ - V-)
  - Vout = A*($V_{control}$ – $V_{potentiometer}$)
- What is Vout when $V_{potentiometer} < V_{control}$?
- What is Vout when $V_{potentiometer} > V_{control}$?





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Motivate Digital Input

- Could provide Analog output from microcontroller with D2A
- …but, D2A is somewhat expensive
- Communicate position using single *digital* output
  - Look at output over time period
  - How much of the time period is it high/low?
  - Use to communicate more than 1 bit of data

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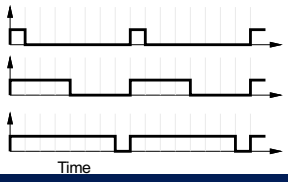
PWM – Pulse Width Modulation

- **Provide pulses at some fixed frequency (490Hz)**
- **Vary how long the pulse is high**
  - Vary the *width* of the high pulse
- **Use that to communicate value (position)**



Preclass 3: Percentage of time each case is high?

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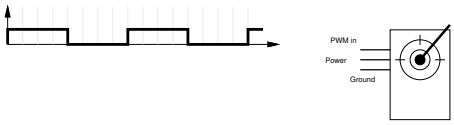
Servo

- **Puts some control smarts in servo package**
- **Takes PWM input to specify position**
- **Senses shaft rotation and engages motor to move to specified position**



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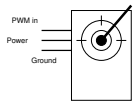
Servo Smarts

- **Could just do all this control from processor**
  - Sense position, drive motor
- **Often cheaper to offload that little control from processor**
  - Including saves pins on (wires to) processor



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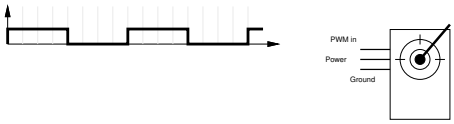
PWM

- **If divide into 8 slots per PWM period, how many bits can we communicate?**
  - Generalize N slots?



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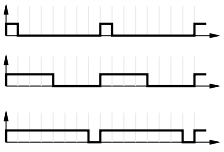
PWM Encoding with Digital Logic

- **Set PWM_CLK = slots*PWM_freq.**
- **So, if use PWM_freq=490Hz and 8 slots**
  - PWM_CLK freq = 3920 Hz
- **How convert digital value to PWM sequence?**
- **always @ (posedge PWM_CLK)**
  - cnt<=cnt+1;
  - PWM<=(cnt<=digital_value);



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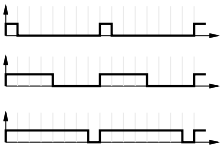
PWM Decoding with Digital Logic

- **How convert PWM input to digital number?**
- **always @ (posedge PWM_CLK)**
  - pwm_pos<=pwm_pos+1
  - If (PWM) cnt<=cnt+1
  - If (pwm_pos==max)
    - digital_out<=cnt;
    - cnt<=0;
    - pwm_pos<=0;



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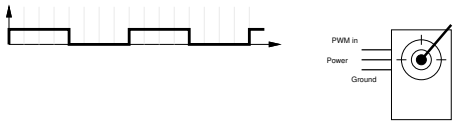
SERVO REVIEW

- **Servo = motor+sensor+control**
- **Takes PWM input to specify position**
- **Control: Senses shaft rotation and engages motor to move to specified position**



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BIG IDEAS

- **Information world can interact with physical world**
  - Sense – read state of physical world into bits for computation
  - Actuate – have bits control physical world
    - Turn on/off, move, position
- **Connect sensing and actuation to control**
  - Computers support computation to realize control and close-the-loop
  - Even with noisy actuators and external disturbances

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LEARN MORE @ PENN

- **Courses**
  - ESE3500 – Embedded Systems
  - ESE4210 – Control for Autonomous Robots

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REMEMBER

- **Feedback including lab**

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