Phys 253 - Lecture 3:

- Lab 2 Wrap-Up
- Robot Design – get started!
- Mechanical Design Elements
- Lab 3 info – Analog-to-Digital conversion (A/D)
- Electronics tips (grounding, power conditioning)

Lab 2 Wrap-Up

•**Capacitors** – electrolytic capacitors have polarity, may explode if inserted backwards

+

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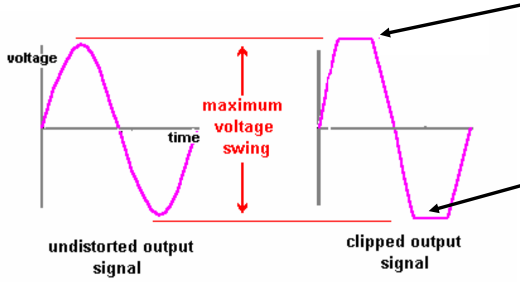
•**Gain** – make sure that gain does not saturate the signal, this will generate unwanted noise after filtering.



Sharp corners have high-frequency noise

Saturation looks like DC signal!

Robot design: Golden Rules

1. Do not over-estimate the amount of time you have available!!!!

   1.a. Do not under-estimate how long soldering / machining / debugging takes.

2. Keep designs SIMPLE and ROBUST

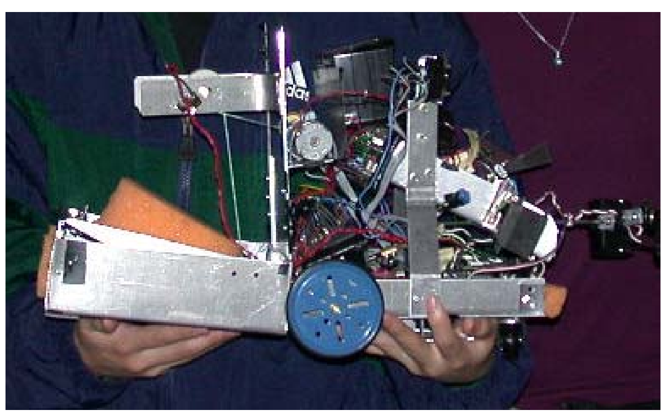
3. Build for RELIABILITY – add complexity later

4. Work hard at the design stage to save yourself time and frustration at the debugging stage

The GOOD, the BAD, and the UGLY…..

THINGS THAT WE'VE SEEN GO WRONG:

- Ineffective or wasteful division of labor/ **poor team communication** / bad time management
- Over-ambitious designs for the time available (and for the need of the competition)
- Good design but unreliable prototyping (**loose wires** etc..), bad soldering



Robot design: Design review (mid-June)

• Clearly identify the FUNCTIONAL REQUIREMENTS of your robot (What will it do? How fast?)

• Have a COMPLETE MECHANICAL DESIGN, with calculations backing up your choice of gears etc..

• CALCULATE where possible any parameters pertaining to your robot design. For example:

- What is the speed of the doll-handling mechanism?
- What is its estimated time to travel the course?
- How many dolls do you expect to transfer in 3 minutes?

•Identify what HANDY BOARD RESOURCES (digital inputs, analog inputs) you will use.

Robot design: Design review

• ESTIMATE any quantities that you can't measure easily. This can include various masses.

• Provide detailed CIRCUIT SCHEMATICS and MECHANICAL SKETCHES or drawings. Keep in mind that this will likely become part of your final report, so any work you put into it now will save you time later.

• Provide block diagrams of ground and power routing.

• Come to the review prepared to answer detailed questions to defend any part of your design.

THE MORE DETAIL YOU SHOW US, THE MORE WE CAN HELP YOU!

Robot design: Essential elements

MECHANICAL DESIGN

- Chassis
- Drivetrain (speed vs torque, ground clearance)
- Steering (proportional steering, diff. drive?)
- Gripper / doll handling

EE / SENSORS

- Sense tape
- Sense IR
- Sense objects
- Sense dolls
- Sense terrain

Robot design: Essential elements

EE / CIRCUITS (cont)

- Motor driver circuits
- IR detector circuit
- Tape following
- Power / ground distribution

SOFTWARE / PSEUDOCODE ALGORITHM

- Tape following routine (PID control)
- Navigation and orientation (based on IR / tape / terrain)
- Collision and obstacle avoidance
- Doll detection and error handling
- Recovering from the unexpected (eg. Completely lost, doll out of place, etc..)

Robot design: Performance criteria

- Speed and maneuverability
- Power / traction / ground clearance
- Accuracy in tape following,
- IR navigation, motor control, sensors
- RELIABILITY

Robot design: Performance criteria

- Speed and maneuverability
- Ruggedness / power / traction / ground clearance
- Accuracy in tape following

Chassis and drivetrain design:

a = F/m →

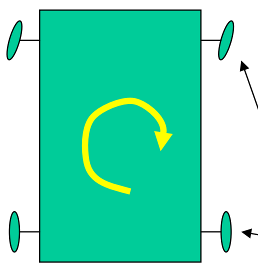
- Minimize mass ?
- Minimize yaw moment of inertia
- Optimize drive gear ratios
- Ensure a stable platform (no tape sensor oscillations) – **stiffness!**

Robot design: Performance criteria

- Speed and maneuverability
- Ruggedness / power / traction
- Accuracy in tape following

$$I = \sum_i m_i r^2$$

Keep masses near rotation axis



Chassis and drivetrain design:

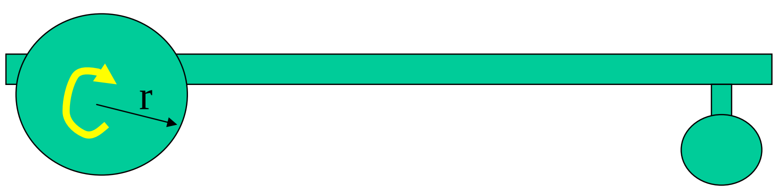
- Minimize mass ?
- Minimize yaw moment of inertia
- Optimize drive gear ratios
- Ensure a stable platform

Wheel and mass locations

Robot design: Performance criteria

- Speed and maneuverability
- Ruggedness / power / traction
- Accuracy in tape following

ω, T



Acceleration:

$a = F/m$

$F = T/r \rightarrow a \sim 1/r$

Speed:

$v_{max} = \omega_{max}\, r$

Chassis and drivetrain design:

- Minimize mass
- Minimize yaw moment of inertia
- Optimize drive gear ratios
- Ensure a stable platform

Robot design: Performance criteria

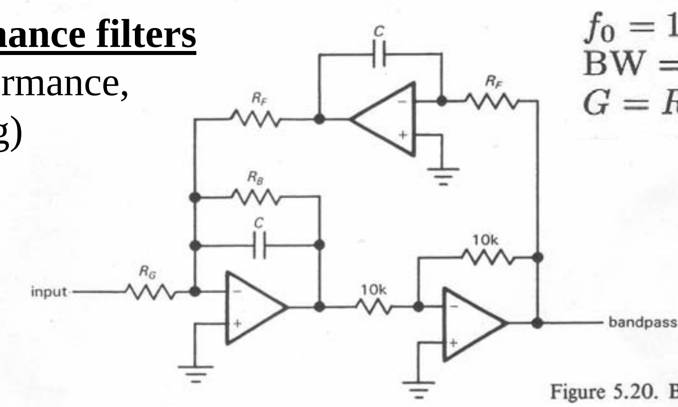
IR navigation, motor control, sensors

Electronics:

- Use proper grounding, clean power
- Shield sensitive circuits
- Use appropriate circuits, whenever required:
  - Multiplexing several sensors into one input signal
  - Higher-order filtering for IR detection

Robot design: Performance criteria

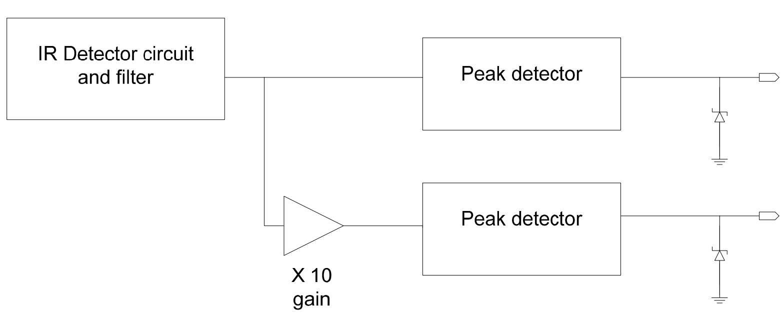
Higher-performance filters
(very good performance,
difficult to debug)



$$f_0 = 1/2\pi R_F C$$
$$BW = 1/2\pi R_B C$$
$$G = R_B/R_G$$

Figure 5.20. Biquad active filter.

Gain switching:



Robot design: Performance criteria

- RELIABILITY

Mechanical reliability:

- Sturdy design / construction (Stiffness!!)
- Proper tolerances
- **Ensure that driving forces >> friction / load**
- Keep the design simple

Electrical Reliability:

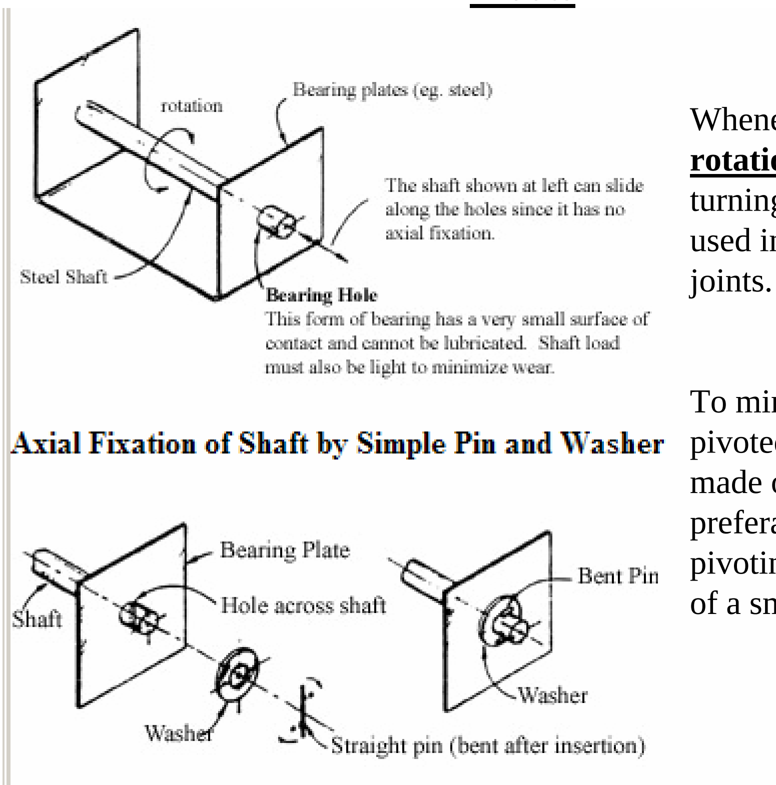
- Use connectors and a properly laid out wiring harness
- Ability to fix / replace burnt-out components

An introduction to (some)
Mechanical Design Elements

Look for inspiration:

- Robots from previous competitions
- Common devices (printers, CD players, toys, etc)
- Course notes and textbooks from other classes, **http://pergatory.mit.edu/2.007/** (design lectures and handbook)
- Design catalogs (McMaster-Carr, Small Parts)

Pivots

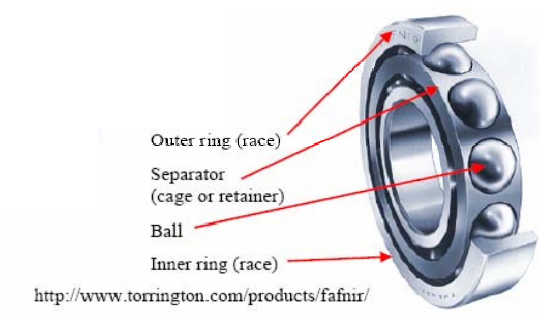


Whenever possible, **rotation** of pivoted or turning joints should be used instead of sliding joints.

To minimize friction forces, pivoted joints should be made of hard materials, preferably steel, and pivoting elements should be of a small diameter.

Images from MIT 2.007: http://pergatory.mit.edu/2.007/lectures/lectures.html

Bearings and Bushings



Oilite bushings
(85% bronze, 15% oil)

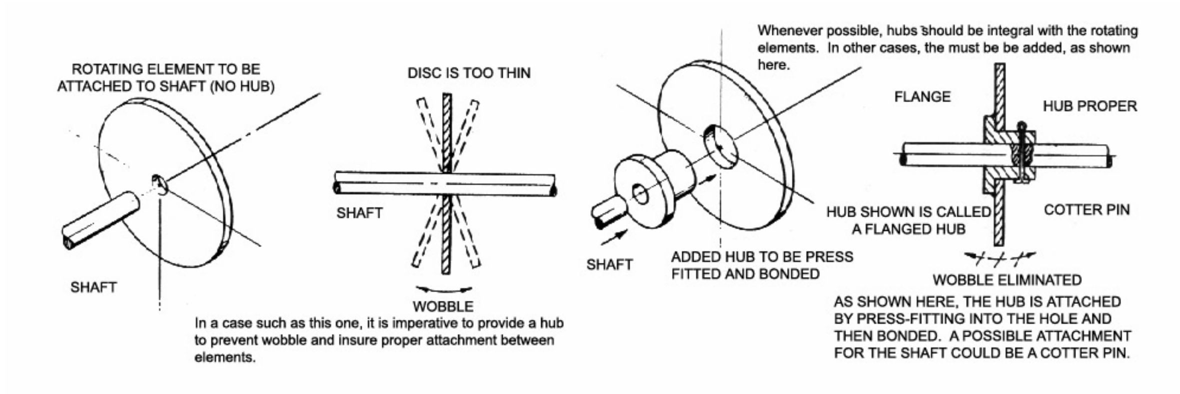
Bearings provide decreased friction and longer life for rotating and sliding parts, but need careful alignment and mounting.

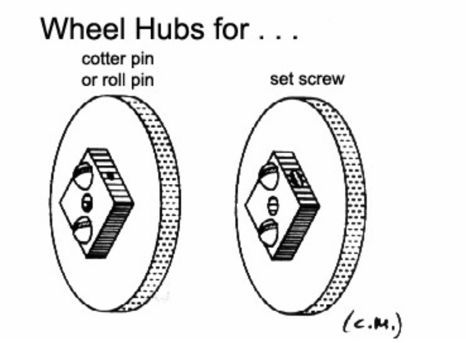
Typical steel bearing housing tolerances are ~0.0001” to 0.0005”

Plastic and brass bearing/bushings are much more tolerant.

Images from MIT 2.007: http://pergatory.mit.edu/2.007/lectures/lectures.html

Hubs





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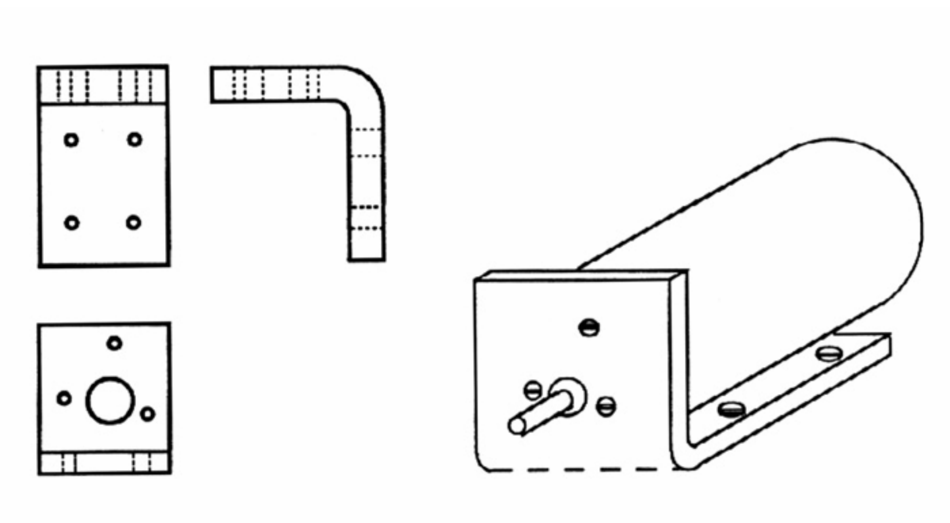
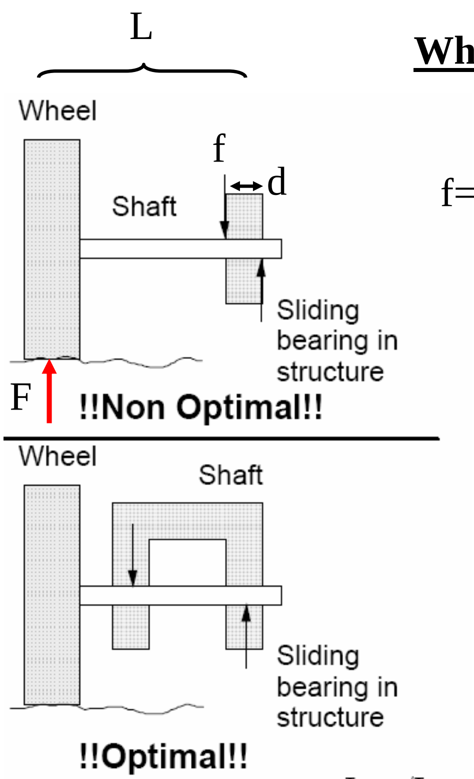
Motor mounts



Drill motor holes after bending to avoid distortions.

Images from MIT 2.007: http://pergatory.mit.edu/2.007/lectures/lectures.html

Wheel mounts



$f = F*L/d$

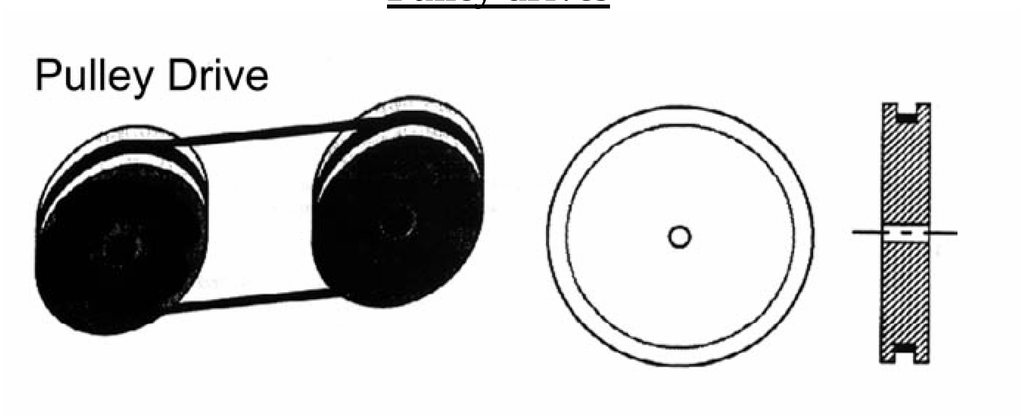
Supporting the robot mass on the wheels, can generate enormous forces in the bearing or the bushing used in the motor.

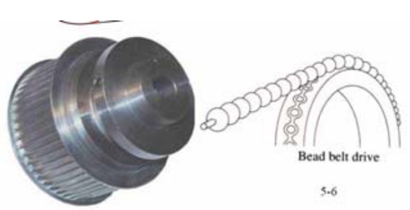
Increasing the distance between support points, and moving them closer to the wheel decreases the forces.

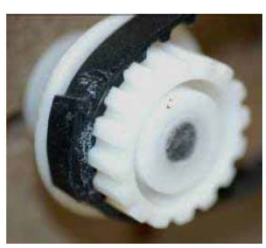
Images from MIT 2.007: http://pergatory.mit.edu/2.007/lectures/lectures.html

- $L_{shaft}/L_{bearing\ spacing} < 1$ and the shaft can be cantilevered
- $L_{shaft}/L_{bearing\ spacing} > 3\text{-}5$ and the slope from shaft bending might overload the bearings, so provide adequate clearance

Pulley drives





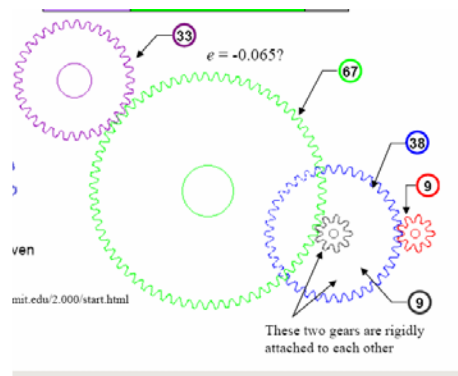


Images from MIT 2.007: http://pergatory.mit.edu/2.007/lectures/lectures.html

Gears

Bevel gears

Rack and pinion



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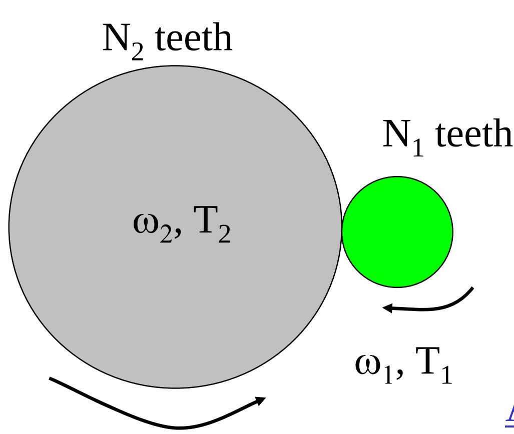
Gears



Torque:

$T_2 = T_1 (N_2/N_1)$

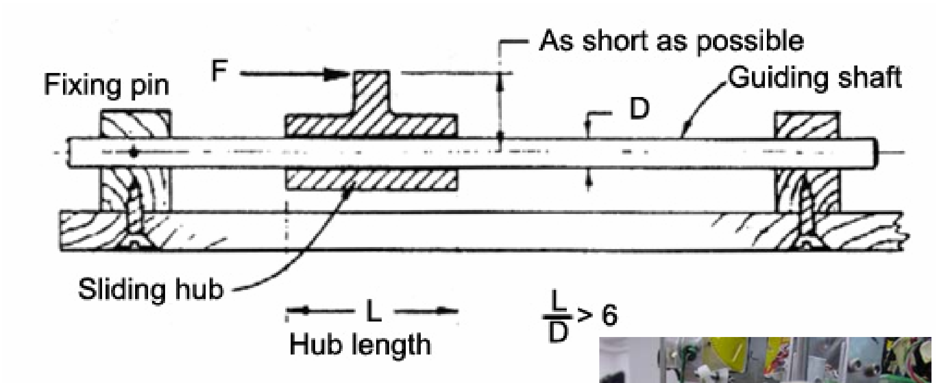
Angular velocity:

$\omega_2 = \omega_1 (N_1/N_2)$

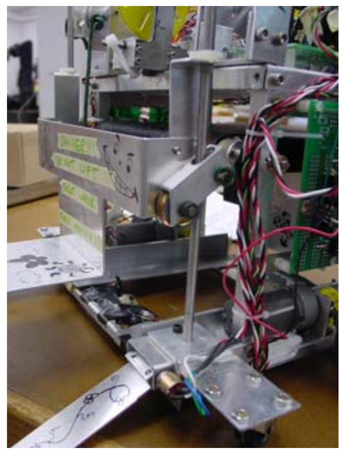
Slower = more torque. Faster = less torque

There are practical limits to the torque you can transmit through gears. Meccano gears will split under excessive torque

Sliding bearings



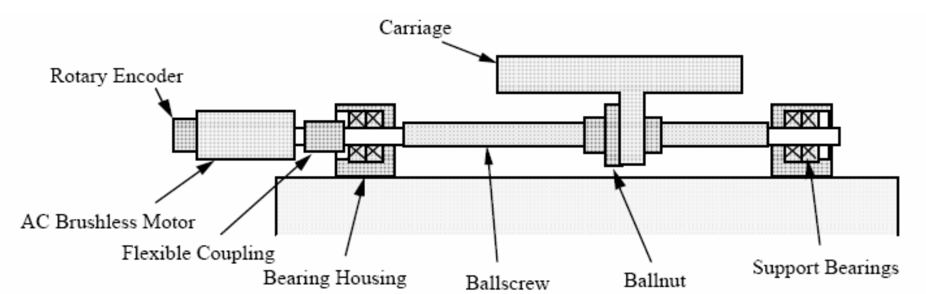
"Linear bearings are ~10x more expensive that rotating bearings although they work really well. Linear systems have been used successfully in 253 but ~50% of such devices have had major sticking problems. Homemade linear bearings systems are particularly problematic under heavy load." (Robin Coope)

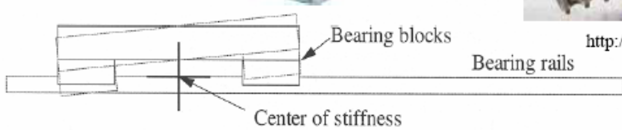


Linear stage using pulleys on 2005-winning robot

Images from MIT 2.007: http://pergatory.mit.edu/2.007/lectures/lectures.html

Lead screws



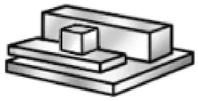


http://www.thomsonindustries.com/industrl/ti090600.htm

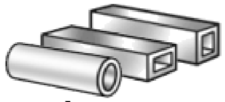
Images from MIT 2.007: http://pergatory.mit.edu/2.007/lectures/lectures.html

Structural / linkages

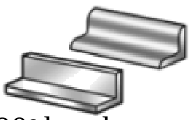
Stock aluminum available:



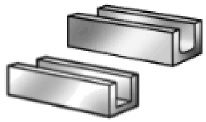
Sheet / Bar



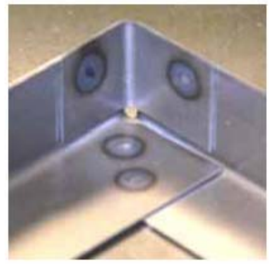
Tube

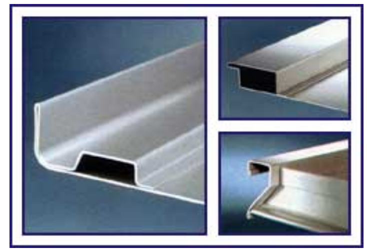


90^o bracket

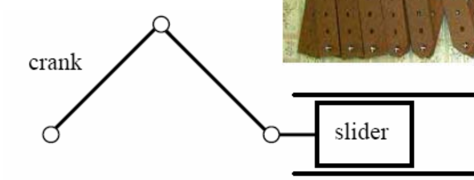


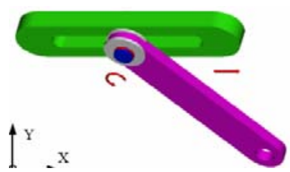
U-channel





Design for low weight and maximum stiffness!





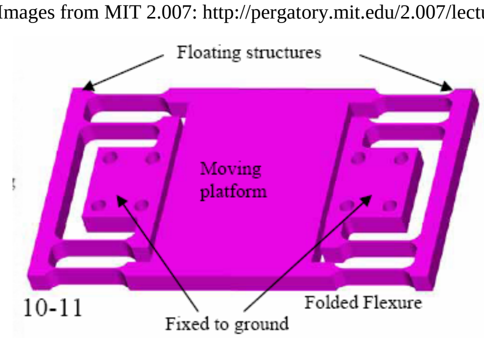
Images from MIT 2.007: http://pergatory.mit.edu/2.007/lectures/lectures.html

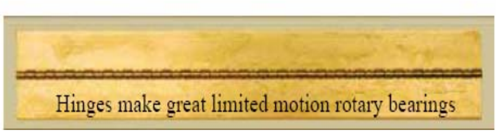
Flexure and hinges

Hinges, flexing elements can be simple solutions for a limited range of motion.

Some flexure designs can provide mechanical reduction for highly accurate positioning (nm).

Images from MIT 2.007: http://pergatory.mit.edu/2.007/lectures/lectures.html





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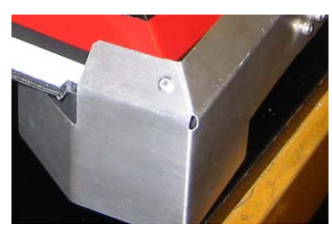
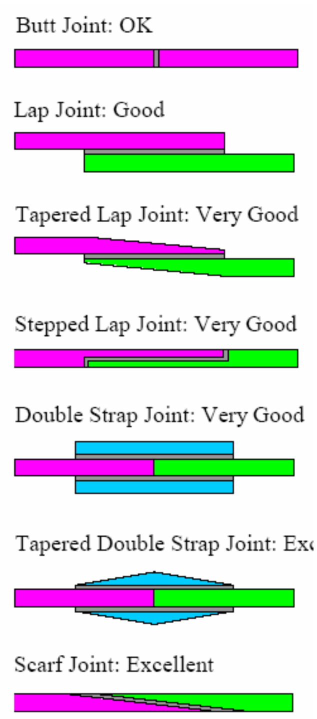


Flexure used for bumpers (microswitch underneath)

Adhesives



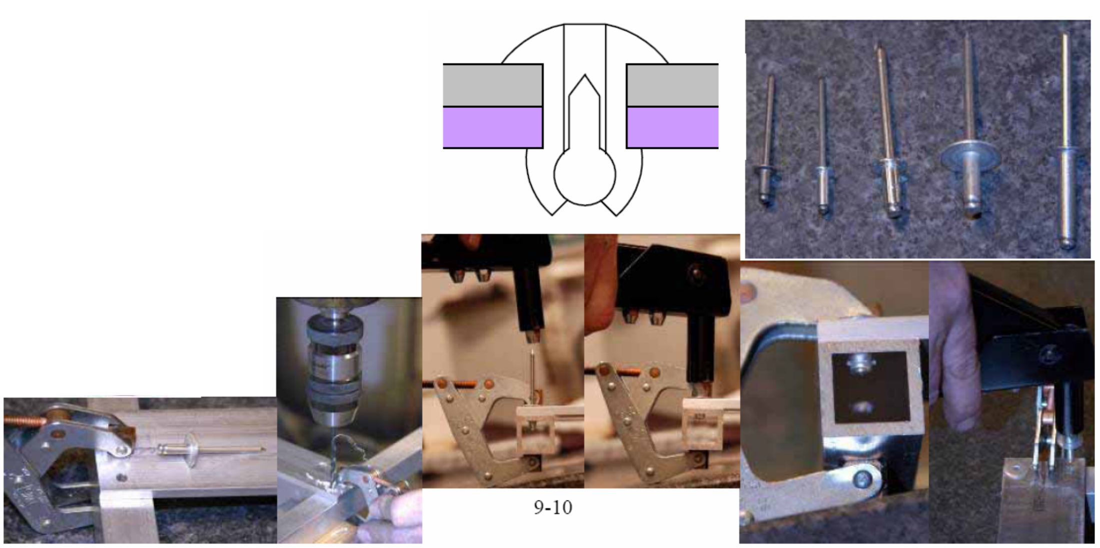
Adhesives in the 253 lab:

- Epoxy
- CA glues (superglue)
- Hot glue
- Adhesive tape (double sided)
- Loctite

Remember to clean and degrease surfaces to be glued.

Images from MIT 2.007: http://pergatory.mit.edu/2.007/lectures/lectures.html

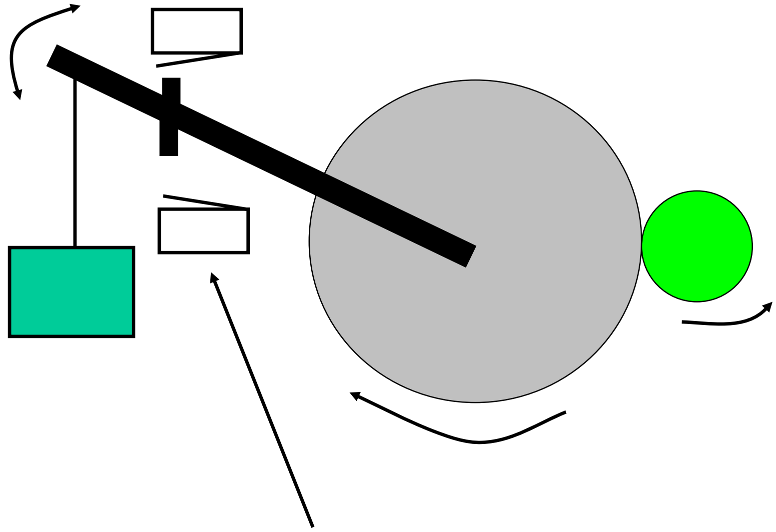
Riveting



Riveting is relatively easy but permanent – for our purposes, screws are a much better and forgiving alternative.

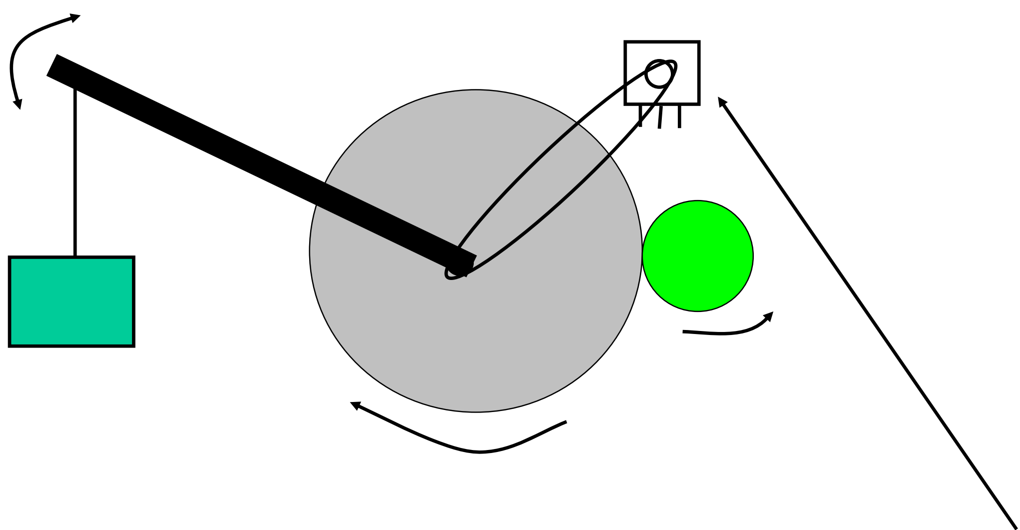
Images from MIT 2.007: http://pergatory.mit.edu/2.007/lectures/lectures.html

Robot design: Motion control



Use limit switches to determine end points of motion when using a DC motor.

Robot design: Motion control



You can also use a potentiometer or other type of rotary sensor or encoder to determine the gear or arm position exactly. This can also be turned into a servo system (see Lab 5).

Robot design: Motion control

The servo you are provided with can give good position accuracy though at low torque and low speed. No limit switches or other sensors are required (see IC manual for C commands)

Robot design: General Suggestions

• Keep HandyBoard easily accessible (read LCD screen, swap HB when you inevitably fry it)

• Make all the electronics easily accessible and wired in through connectors. (Same reason….). Same with batteries.

• Solder all your circuits. Make circuits modular.

• Use proper connectors (at least use the header strips). Wires plugged directly into the HB will come loose. (Label all wires properly too so you (or your teammate) can plug them back in if they come loose).

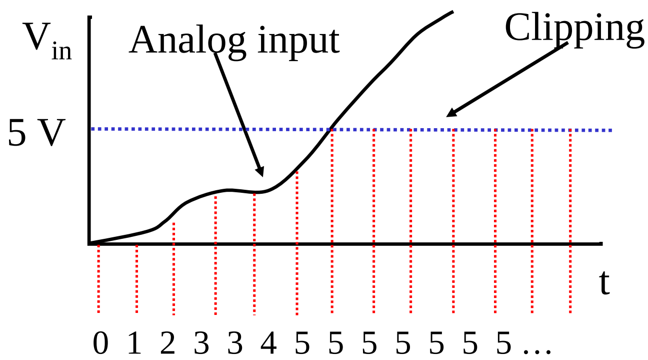
• Keep in mind your robot will at some point ram into a wall or fall off a cliff. Make it rugged. Don't make it too sharp or pointy if you want people to catch it…

Start of Lab 3 Material

<u>A/D Conversion</u>

<u>**Handy Board:**</u> 8-bit A/D converter, 0-5V range, 7 channels

Getting the correct range in your input signal:



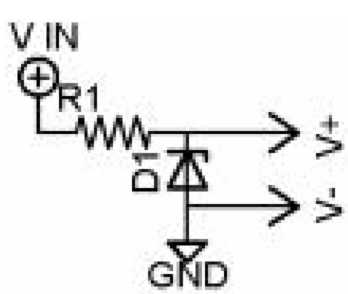
Digital reading:

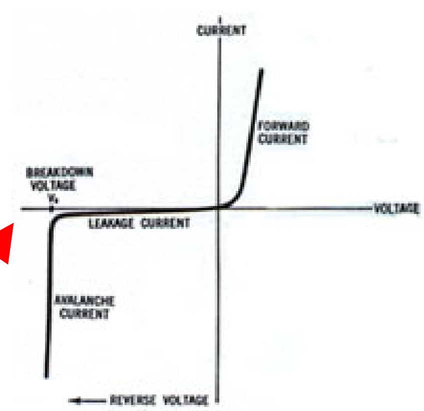
> The highest voltage reached by your input must be less than the maximum range of the A/D to avoid clipping or saturation.

A/D Conversion

<u>**Use 5V Zener Diodes to protect your Handy Board**</u>

Zener diodes (5V1)





Current-voltage characteristics of a typical P-N junction.

> Zener diodes conduct under reverse bias when a specific voltage is exceeded – in our case 5.1V

A/D Conversion

Handy Board: 8-bit A/D converter, 0-5V range, 7 channels

Getting the correct range in your input signal:

8 bits: 5 V → 1111 1111

0 V → 0000 0000

Smallest detectable voltage = 0000 0001

1111 1111 = 255, so smallest voltage is = (1/255)* 5 V = 20 mV

The lowest voltage detectable by the A/D is dependent on the number of bits. This is also the resolution of the A/D.

An aside – error types:

Resolution: The smallest detectable change in the measurement.

eg: 2.000 °C vs 2.001 °C
Resolution is 0.001 °C

Accuracy: How close the measured value is to the actual value.

eg: Temperature is 20 °C , measured value is 19.001 °C
Accuracy error is ~ 5%

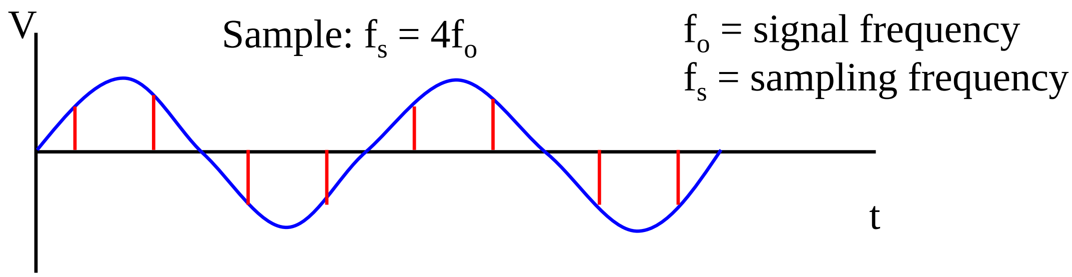
Repeatability / Precision: How close are two different measurements of the same value.

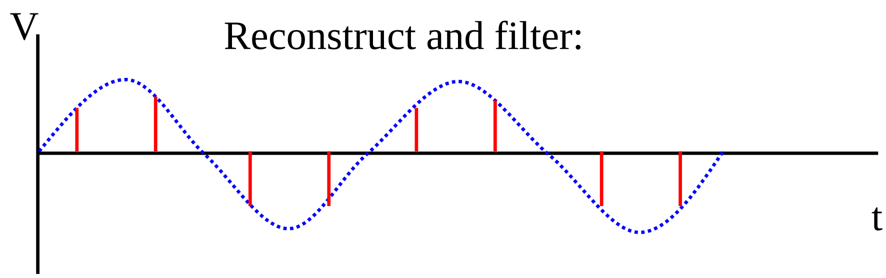
eg: Temp is 20 °C , 1st measurement is 19.001 °C
2nd measurement is 19.003 °C
Repeatability ~ 0.002 °C .

A/D Conversion - aliasing

Maximum input signal bandwidth:

Input signal bandwidth (frequency range) is limited by aliasing:





A/D Conversion - aliasing

Maximum input voltage bandwidth:

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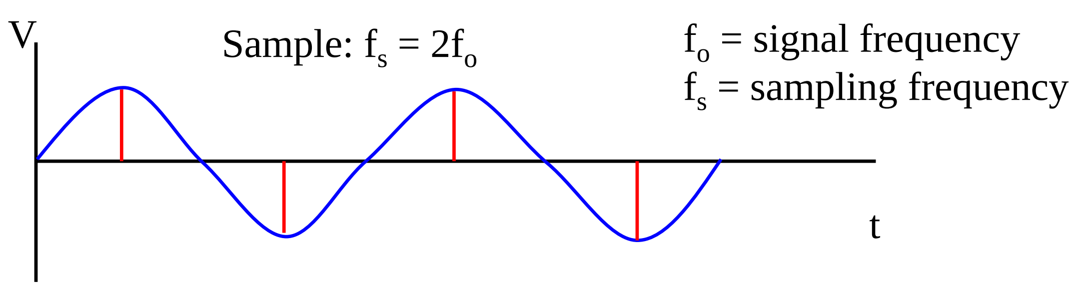
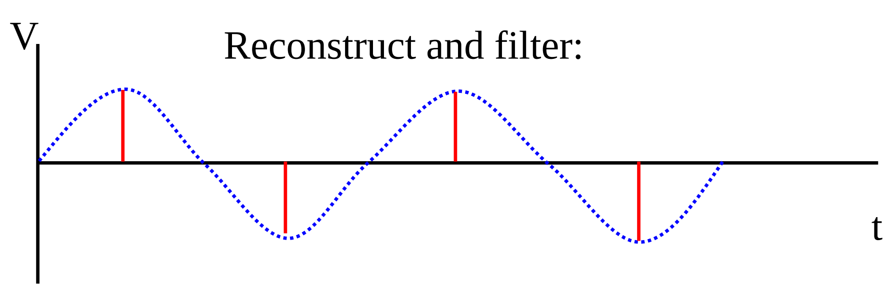


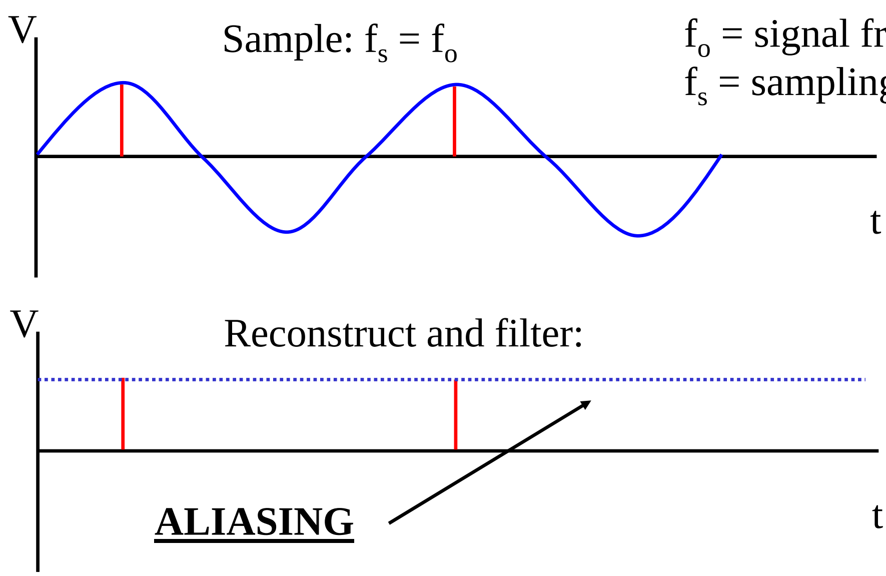


A/D Conversion - aliasing

Maximum input voltage bandwidth:

Input signal bandwidth (frequency range) is limited by aliasing:

f_o = signal frequency
f_s = sampling frequency



A/D Conversion - aliasing

Maximum input bandwidth:

Sampling Theorem: $f_s > 2\ f_o$ to avoid aliasing.

Audio CDs: max bandwidth (f_o) = 18 kHz,
sampling frequency (f_s) = 44 kHz

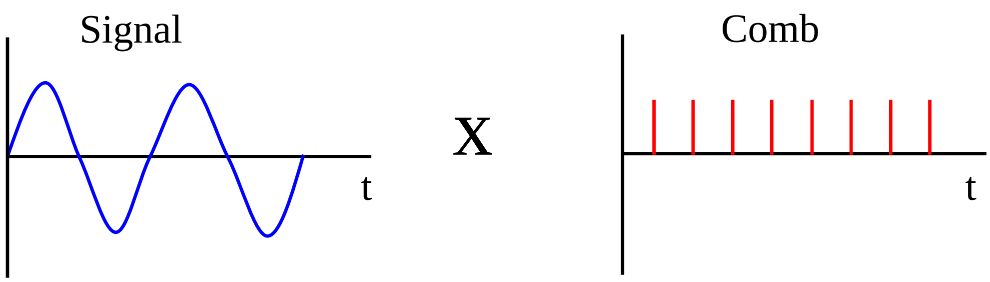
The situation is MUCH WORSE than just “missing out on” frequencies in your signal that are higher than ½ f_s.

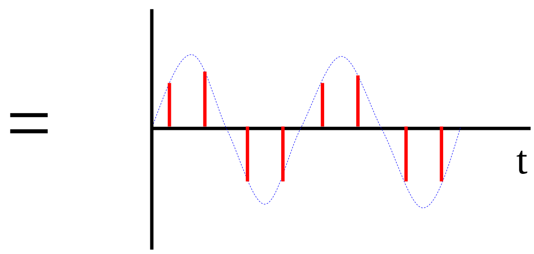
If these frequencies are not removed before the A/D by appropriate filtering, they will be “down-converted” by aliasing and contaminate your signal’s lower frequencies.

A/D Conversion - aliasing

Another look - sampling in the TIME DOMAIN:

Sampling a signal is the same as multiplying it with a unity comb function at the sampling frequency:





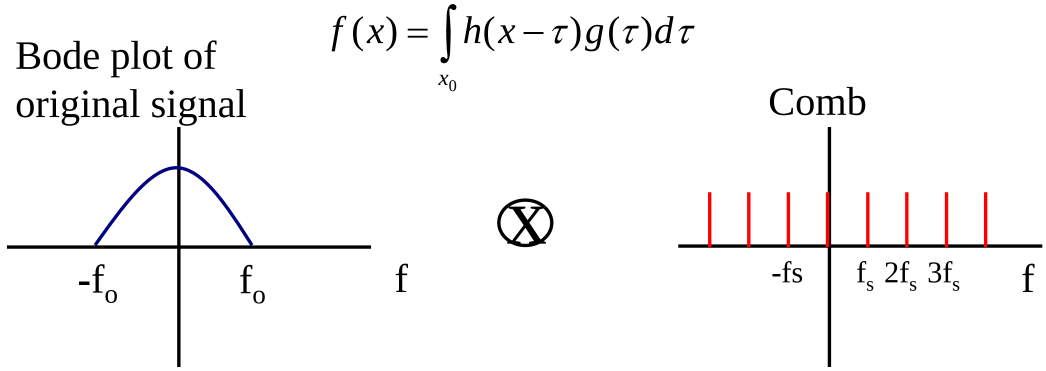
Series of delta-functions with different amplitudes (follow with sine-wave)

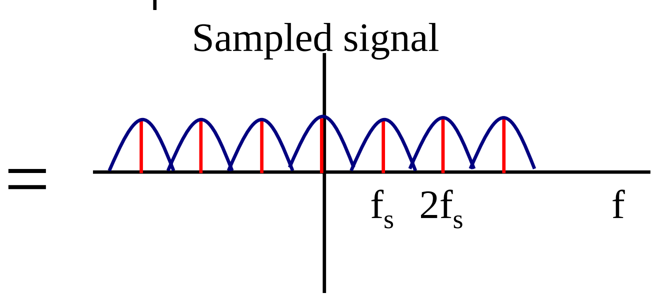
A/D Conversion - aliasing

Another look - sampling in the FREQUENCY DOMAIN:

Multiplication in the time domain = Convolution in the frequency domain:

$$f(x) = \int_{x_0}^{x} h(x-\tau)g(\tau)d\tau$$

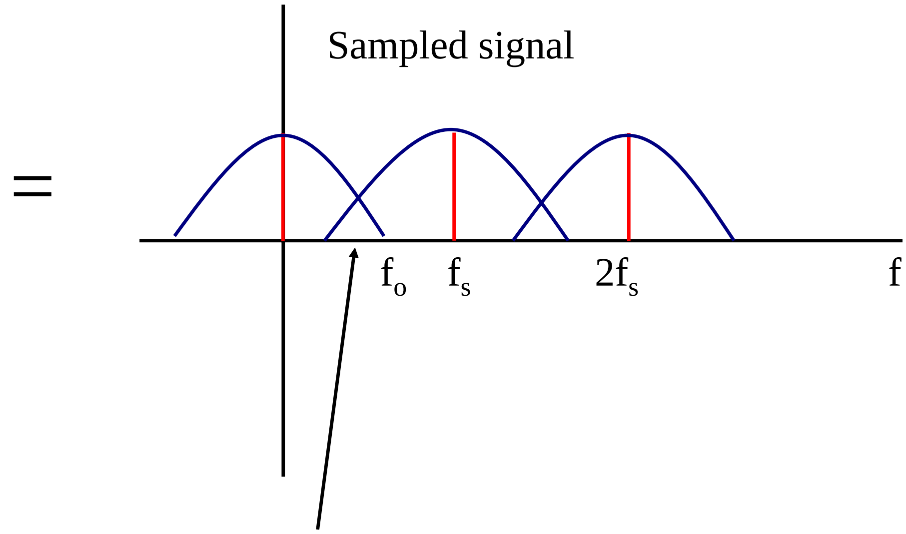




One complete copy of the bode plot of the original

A/D Conversion - aliasing

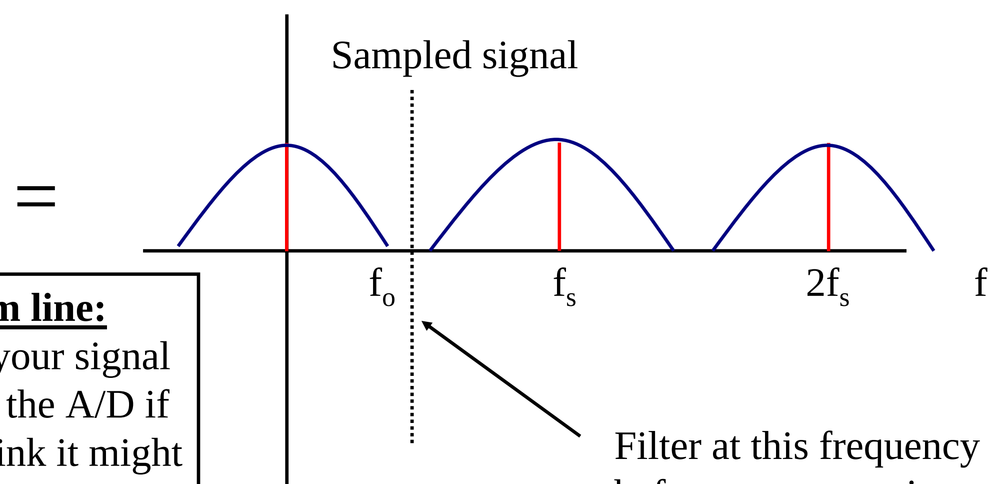
Another look - sampling in the frequency domain:



Aliasing occurs if $f_s < 2f_o$

A/D Conversion - aliasing

Another look - sampling in the frequency domain:



Bottom line:
Filter your signal before the A/D if you think it might have frequency components above $f_s/2$

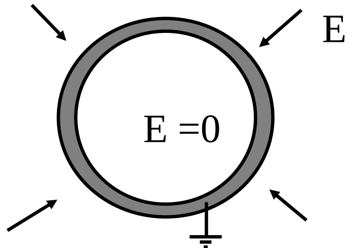
Filter at this frequency before reconstructing signal

No Aliasing : $f_s > 2f_o$

ELECTRONICS TIPS:
Shielding and grounding

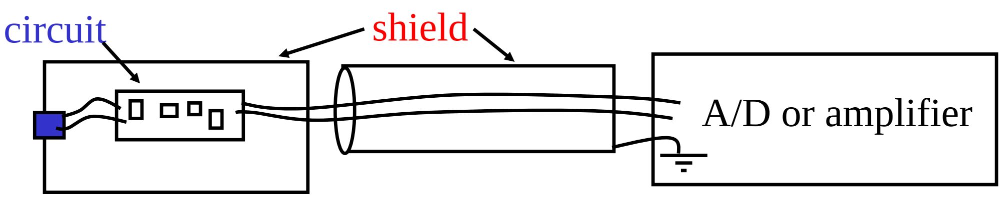
How to keep your low-level signals from being contaminated by noise:

Gauss' law:



E=0 everywhere inside a grounded conducting shell (with no charge inside the shell).

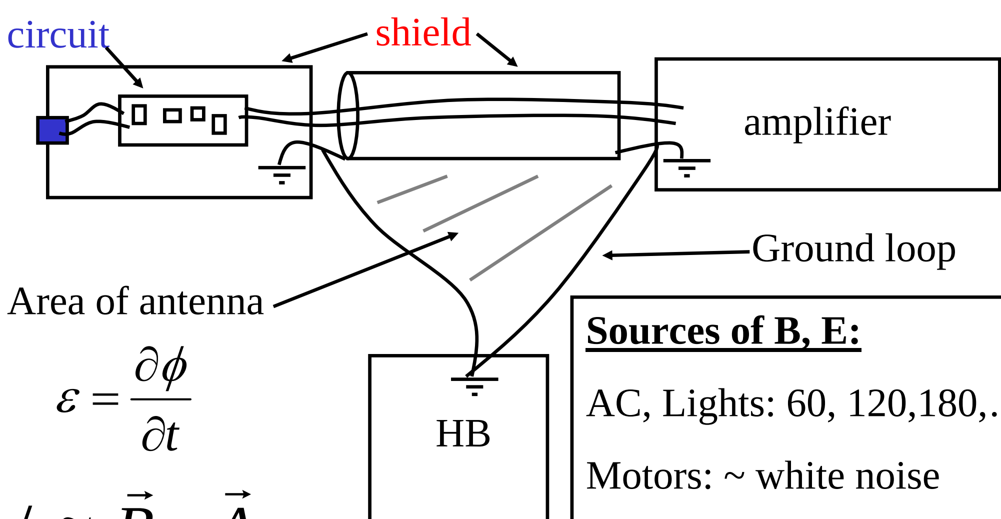
We take advantage of this to shield circuits and wires carrying sensitive signals:



Shielding and grounding

Ground loops:

Improper grounding can lead to noise of its own:



$$\varepsilon = \frac{\partial \phi}{\partial t}$$

$$\phi \cong \vec{B} \bullet \vec{A}$$

Sources of B, E:

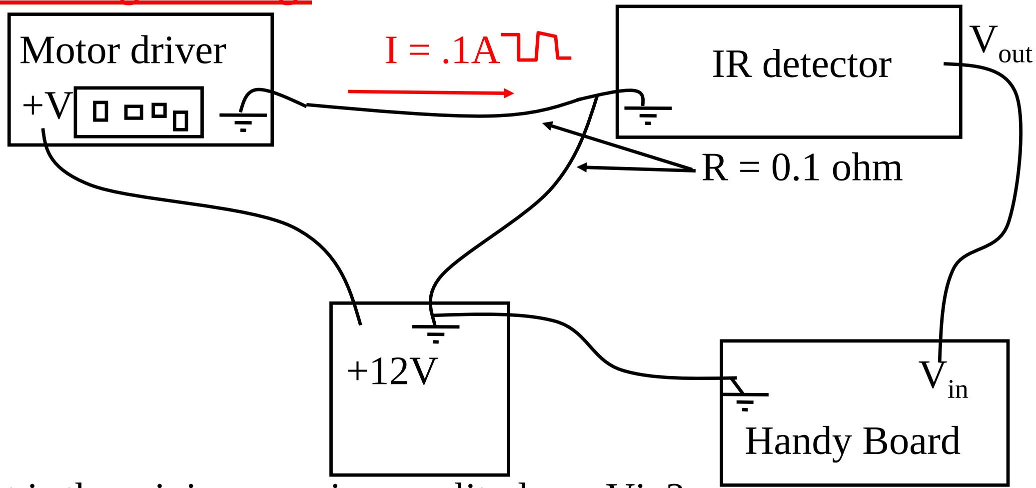
AC, Lights: 60, 120,180,…Hz

Motors: ~ white noise

PWM to motors: PWM freq. +harmonics

Shielding and grounding

More bad grounding:

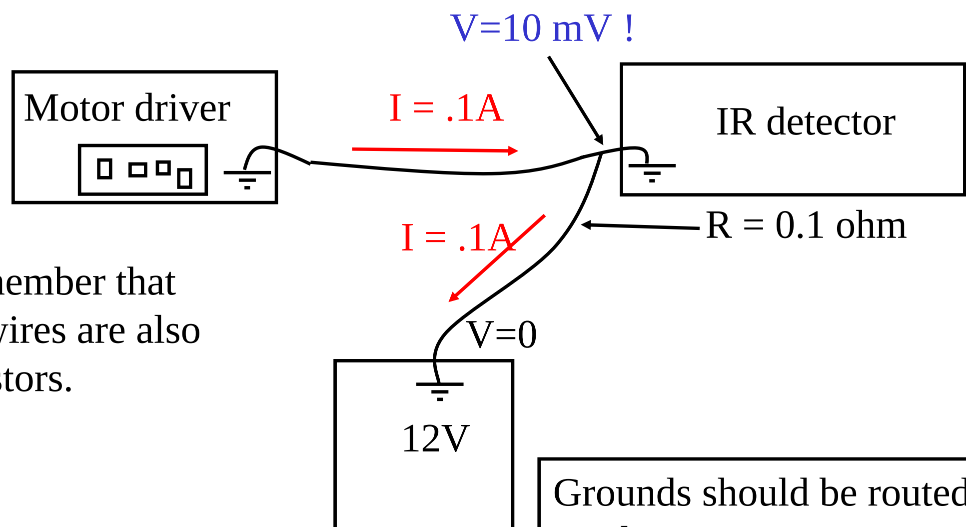


What is the minimum noise amplitude on Vin?

1) 0 V_{pp}
2) .1 V_{pp}
3) 10 mV_{pp}
4) 1 mV_{pp}

Shielding and grounding

Improper grounding can lead to noise of its own:



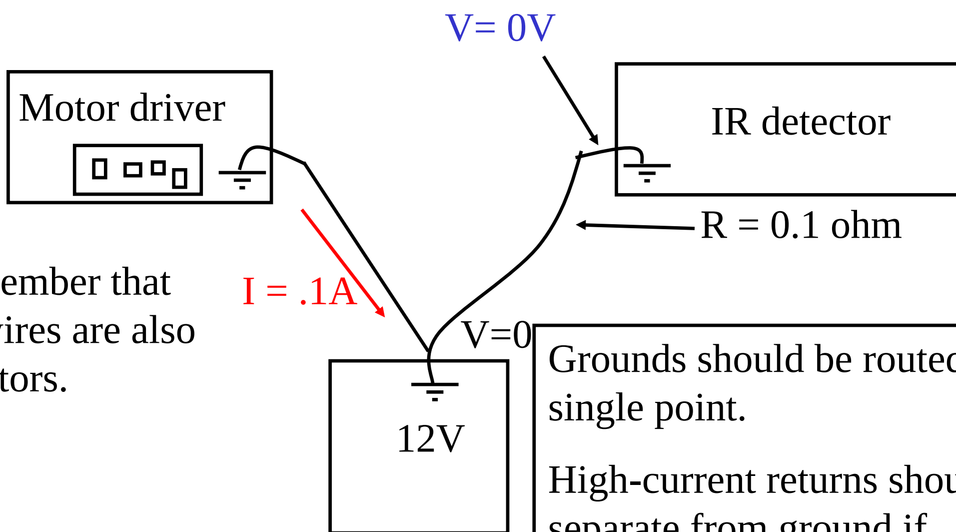
Remember that all wires are also resistors.

Grounds should be routed to a single point.

Shielding and grounding

Proper grounding:

Improper grounding can lead to noise of its own:



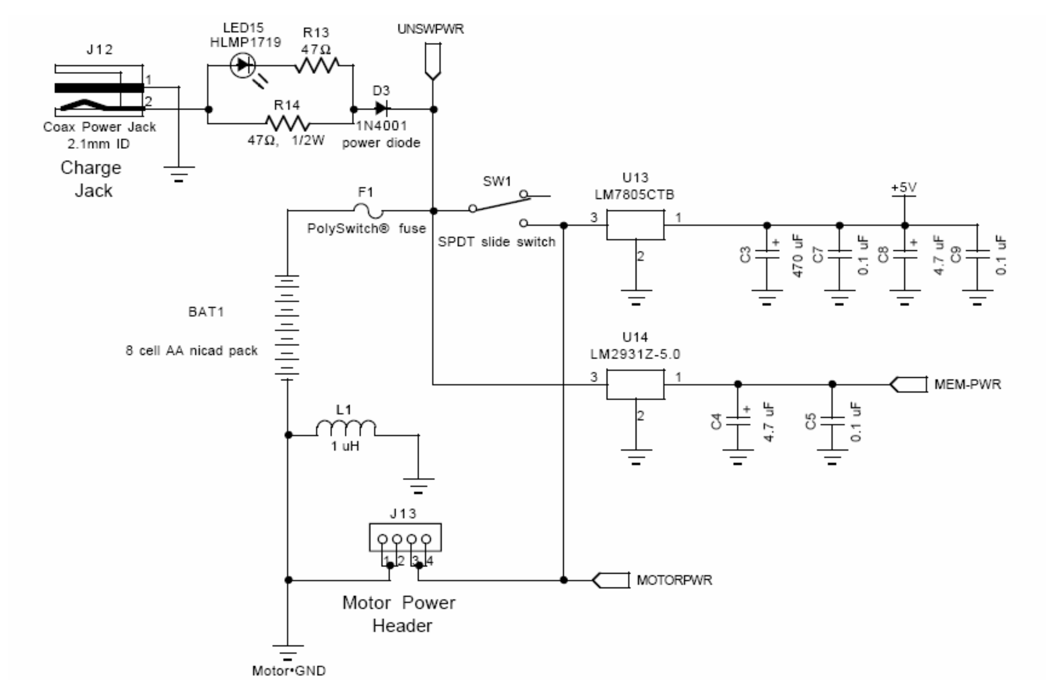
Remember that all wires are also resistors.

Grounds should be routed to a single point.

High-current returns should be separate from ground if possible.

Shielding and grounding

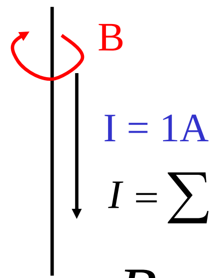
Ground noise isolation

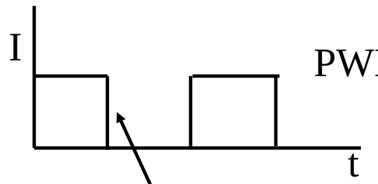


Shielding and grounding

Minimizing noise sources:

High-current, high frequency signals are the worst offenders: The wires running to your motors are a great example of this.





$$I = \sum I_n \cos \omega_n t$$

High frequency components!

$$B \propto I$$

This makes dB/dt large and increases EMF coupled to other loops.

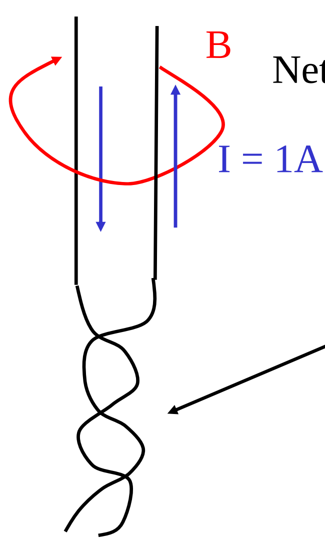
$$\frac{\partial \mathbf{B}}{\partial t} \propto \omega I \sin \omega t$$

$$\varepsilon \propto \frac{\partial B}{\partial t} \bullet A$$

Shielding and grounding

Minimizing noise sources:

High-current, high frequency signals are the worst offenders: The wires running to your motors are a great example of this.



Net enclosed current ~ 0

Pair and twist current carrying wires to cancel B!

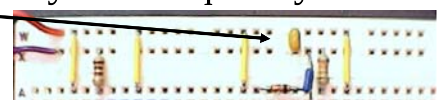
Twisting signal wires also reduces area for inductive coupling.

Power conditioning

Keep your power lines clean of high frequency oscillations:

High-current, high frequency loads in your circuit can propagate voltage fluctuations in your power lines.

• Put a 10 or 100 pF capacitor from power to ground every 1” of circuit board for digital circuits. Possibly less frequently for lower speed analog circuits



• Use a separate power source for your high current, fluctuating loads, or filter and regulate power from such a source before using it as power to op-amps etc..