University of British Columbia
Electrical and Computer Engineering
ELEC291/ELEC292

# Project 2: Magnetic Field Controlled Robot.

Dr. Jesús Calviño-Fraga P.Eng.
Department of Electrical and Computer Engineering, UBC
Office: KAIS 3024
E-mail: jesusc@ece.ubc.ca
Phone: (604)-827-5387

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# Requirements

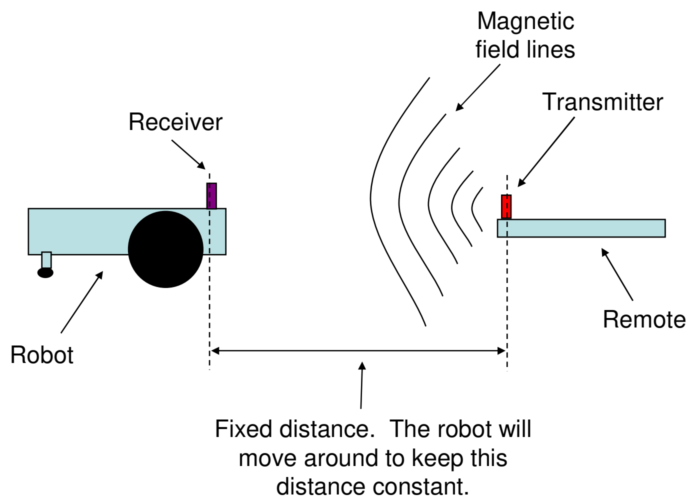
- Two Microcontrollers:
  - Robot is the receiver. It keeps a preprogrammed and configurable distance from the remote (transmitter).
  - Remote is the transmitter. It generates the magnetic field and sends commands to the Robot.
- Programmed in C.
- Both transmitter and receiver are battery powered.
- Discrete MOSFET drivers.
- Remote commands:
  - Turn left.
  - Turn right.
  - Move forward.
  - Move Backward.
- Shortest maximum distance of 50 cm. An acceptable range would be 20cm (min.) to 80cm (max.).

# Microcontrollers

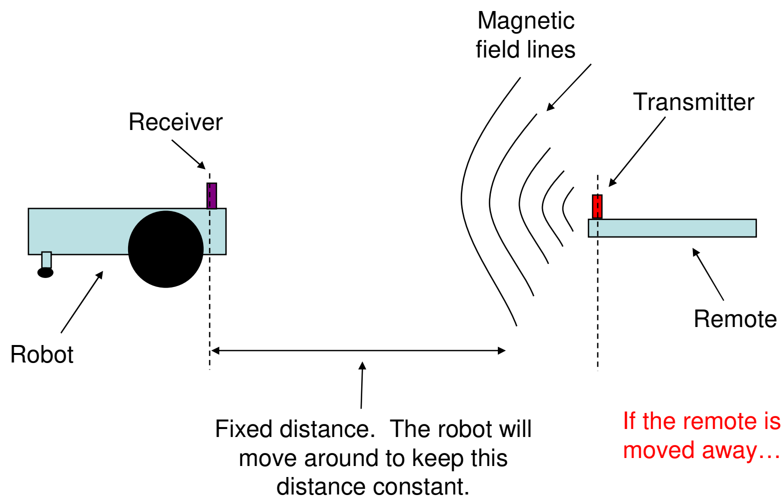
1. The two microcontroller systems MUST be from different families. Some microcontrollers are provided in the project #2 kit: MSP430G2553, PIC32MX130, ATMega328P, LPC824, and STM32L051. You have from previous kits: EFM8LB12 and AT89LP51RC2.
2. One <u>valid</u> combination: the transmitter using the EFM8LB12 (8051 family) and the robot using the PIC32MX130 microcontroller (MIPS family).
3. One <u>**invalid**</u> combination: the transmitter using the LPC824 (ARM Cortex M0 family) and the robot using the STM32L051 (ARM Cortex M0 family) since both microcontrollers belong to the same family.




# Magnetic Field Controlled Robot



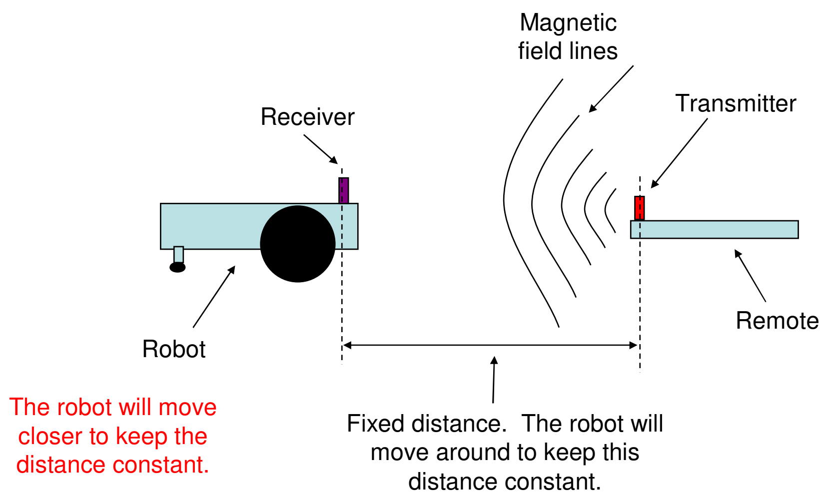
# Magnetic Field Controlled Robot



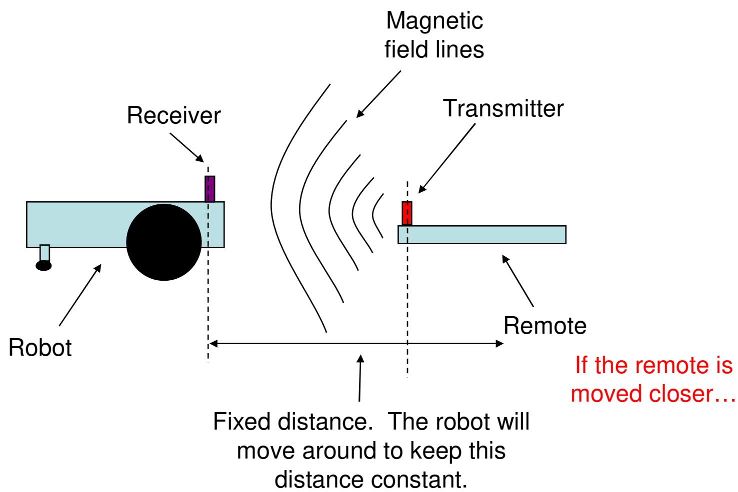




# Magnetic Field Controlled Robot



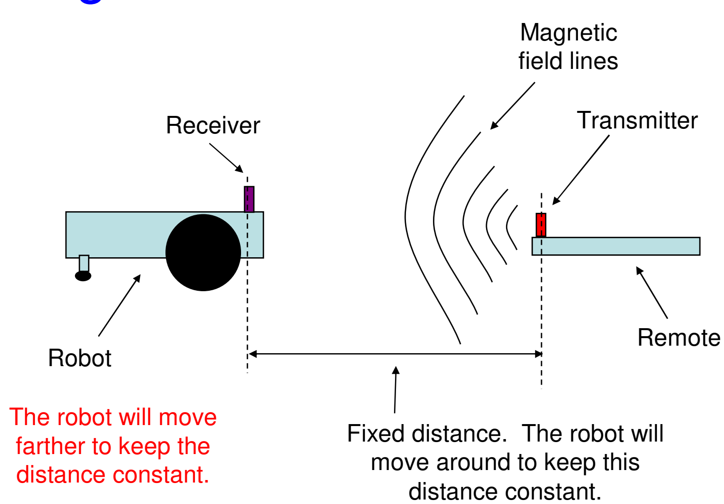
# Magnetic Field Controlled Robot




Project 2 Description



# Magnetic Field Controlled Robot




Project 2 Description

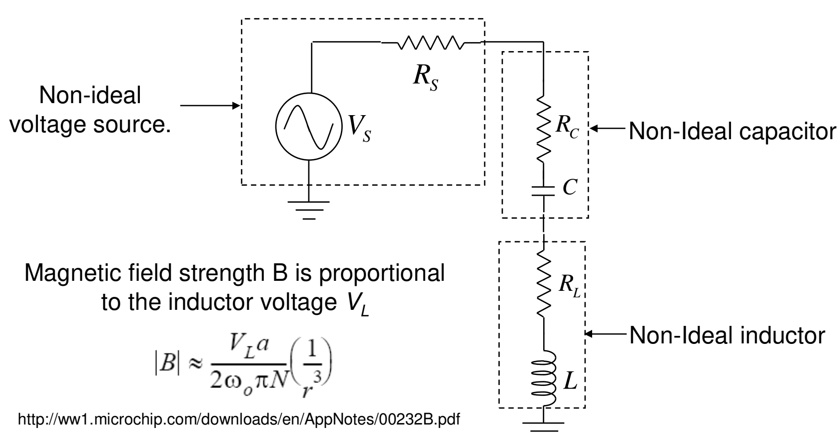
# Transmitter

- It is a series RLC circuit you should know from ELEC202.
- The inductor (L) is provided in the robot kit. You can use any inductor you want!
- For the capacitor (C) you can use the capacitors you already have, but they may not work very well. Optionally you can buy a much better capacitor in local electronics parts stores.
- You need a safe, stable, and reliable transmitter for your project.





# Simplified RLC Transmitter Circuit



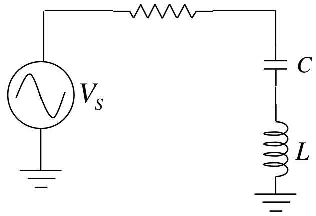

Magnetic field strength B is proportional to the inductor voltage $V_L$

$$|B| \approx \frac{V_L a}{2\omega_o \pi N}\left(\frac{1}{r^3}\right)$$

http://ww1.microchip.com/downloads/en/AppNotes/00232B.pdf

# Simplified RLC Transmitter Circuit

$$R = R_S + R_C + R_L$$



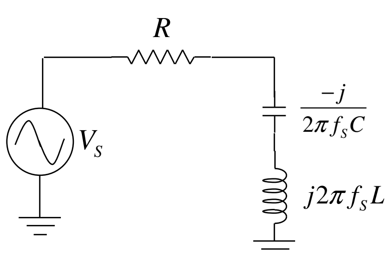

For maximum voltage at the inductor, the circuit must be tuned:

$$f_S = \frac{1}{2\pi\sqrt{LC}}$$

Other factors affect the magnitude of VL. Use phasor analysis!




# Simplified RLC Transmitter Circuit



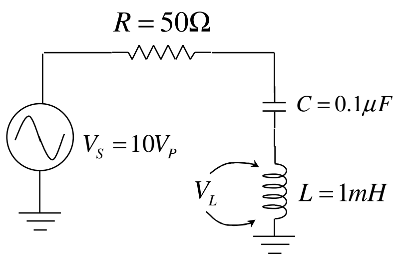

$$i = \frac{V_S}{R - \frac{j}{2\pi f_S C} + j2\pi f_S L} = \frac{Vs}{R}$$

At the tuned frequency this two values are equal!

$$f_S = \frac{1}{2\pi\sqrt{LC}}$$

$$\boxed{V_L = \frac{jV_S 2\pi f_S L}{R}}$$

# Simplified RLC Transmitter Circuit test using function generator.




$$f_S = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{1mH \times 0.1\mu F}} = 15.92kHz$$

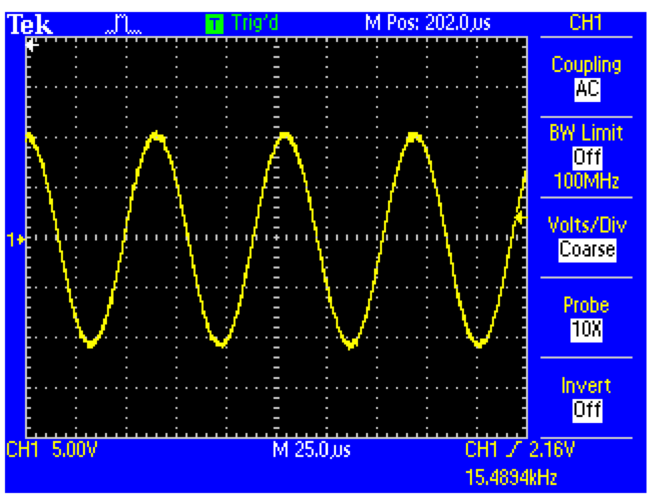
$$i = \frac{Vs}{R} = \frac{10V_P}{50\Omega} = 0.2A_P$$

$$V_L = j \times 0.2A_P \times 2\pi \times 15.92kHz \times 1mH = 20V_P$$

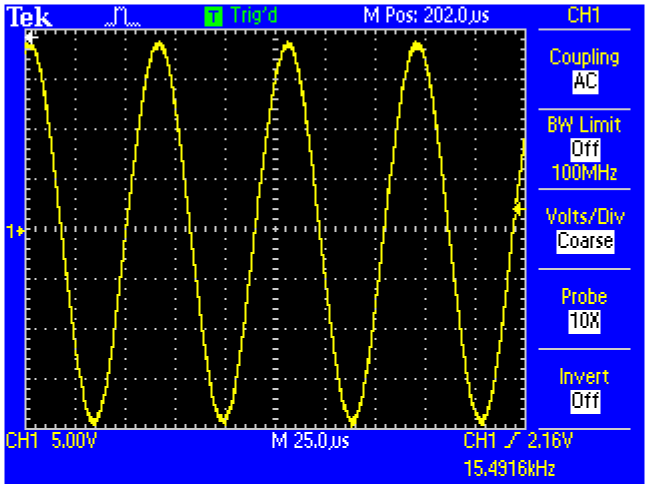
Not good enough. You'll need about 150 $V_p$!




# $V_S$ Using a Function Generator



# $V_L$ From the Circuit Above







# Maximizing $V_L$

- Increase $V_S$.
  - Con: Large source voltages are difficult to handle. Potentially dangerous.
- ~~Increase $f_S$.~~
  - Con: It wont work because $f_s$ is also in the denominator of the magnetic field stre

$$|B| \approx \frac{V_L a}{2\omega_o \pi N}\left(\frac{1}{r^3}\right)$$

- ~~Increase L.~~
  - Con: you'll need to get new inductors. The ones you have are pretty good! Is it also in the magnetic field strength equation?!
- Decrease R.
  - Con: None! Decrease R!

# $V_S$

- It can be an square wave!
- The Fourier Series of a square wave is given by:

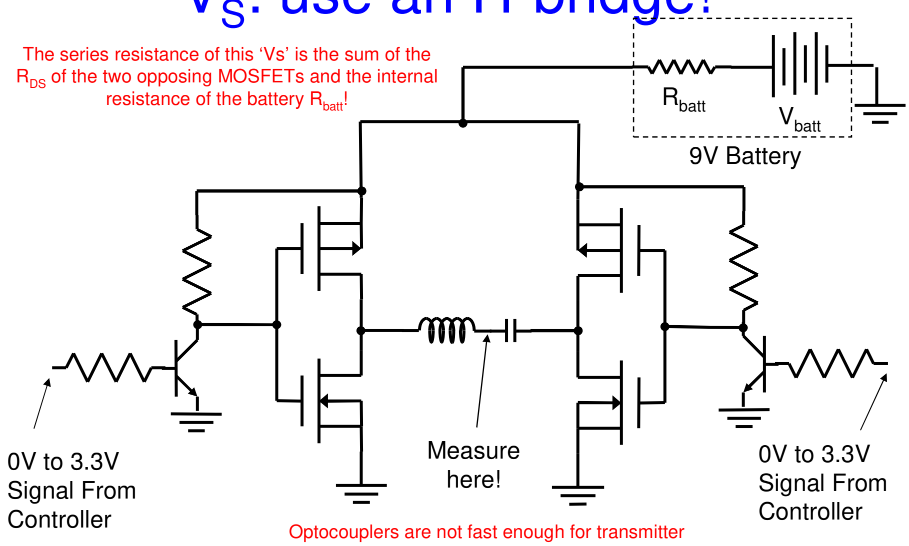
$$x(t)=\frac{4}{\pi}\sum_{k=1}^{\infty}\frac{\sin(2\pi(2k-1)ft)}{2k-1}=\frac{4}{\pi}\left(\underbrace{\sin(2\pi ft)}_{\text{Fundamental}}+\frac{1}{3}\underbrace{\sin(6\pi ft)}_{3^{rd}\text{ harmonic}}+\frac{1}{5}\underbrace{\sin(10\pi ft)}_{5^{th}\text{ harmonic}}+\ldots\right)$$

Bonus: The amplitude of the fundamental is $4/\pi=1.273$ times the amplitude of the square wave!




# $V_S$: use an H-bridge!

The series resistance of this 'Vs' is the sum of the $R_{DS}$ of the two opposing MOSFETs and the internal resistance of the battery $R_{batt}$!




Optocouplers are not fast enough for transmitter frequency! Using 2N3904BJTs instead.

## Finding the Tuned Frequency

- At the tuned frequency the output voltage as indicated in the previous slide is at it maximum: 100s of volts! (I've seen up to 800V! 200V is more common.)
- Use the oscilloscope to CAREFULLY check the signal. The maximum voltage the oscilloscope can take is 300V. Therefore you must use an oscilloscope probe with **10x attenuation**.
- Use the program 'freq_gen' available in connect for each of the supported microcontrollers to find the tuned frequency.




## ☠ ☠ ☠ WARNING! ☠ ☠ ☠

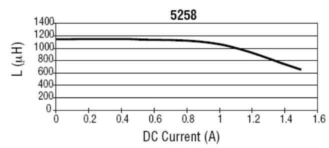
- If you use a low resistance source, like the H-bridge from the previous slides, the peak voltage at both the inductor and capacitor may increase to hundreds of volts! Calculate it using phasor analysis!
  - If you touch the circuit you will get shocked! **DO NOT TOUCH EITHER THE INDUCTOR OR CAPACITOR** terminals when the circuit is on. Safety tip: use an smaller voltage (<100Vp) for development and test. When design/test is done increase the voltage to its maximum.
  - The capacitor must be rated for the generated voltage. Putting a 50V capacitor into a 300V circuit may result in a blown capacitor and/or weak magnetic field.
  - Connect instruments to the circuit that work at the rated voltage. Make sure the oscilloscope probes are set to10X attenuation.

# The Inductor

- DigiKey part number M8275-ND

Don't drop the inductor.
The ferrite core breaks!

| | |
|---|---|
| **Type** | Wirewound |
| **Material - Core** | Ferrite |
| **Inductance** | 1mH |
| **Tolerance** | ±20% |
| **Current Rating** | 1A |
| **DC Resistance** | 0.55 Ohms |





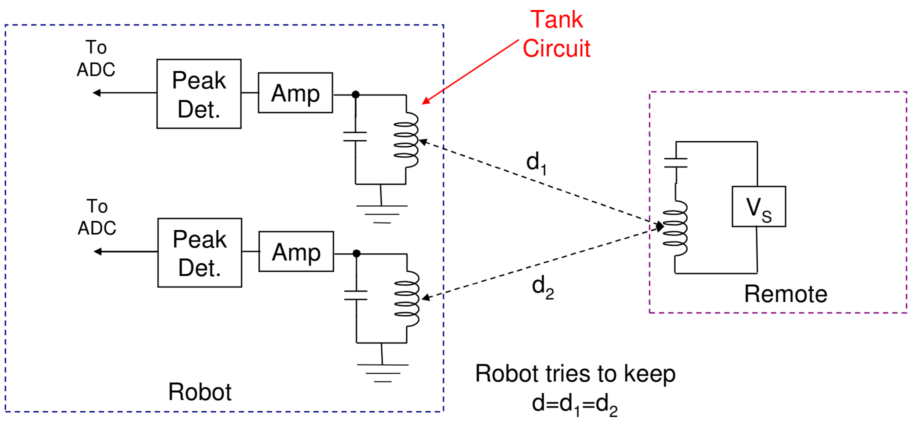



# The Capacitor

- The peak value of the voltage across the capacitor is equal to the peak value across the inductor. The capacitor MUST be rated for the operating voltage! If not:
  - The capacitor may over heat and explode.
  - The capacitor may short circuit and catch fire.
  - The capacitor may introduce too much series resistance.
- Go to RP or Lee's and buy a good capacitor!
- I have a LIMITED stock of 0.1µF @ 300V capacitors. I can give <u>ONE</u> to each team.

# The Receiver

- It requires two inductors to determine which way to move in tracker mode:

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Project 2 Description



# Amplifier and peak detector

- The amplifier can be made using an op-amp in a non-inverting configuration with a gain of around 50 (testing required). Single power supply op-amps (LM358, LM324) seem to work fine.
- The simplest peak detector (diode + capacitor + resistor) works great for this application.
- Select RC for the peak detector so that the ripple is small but the circuit is still fast enough to detect changes in amplitude quickly.
- Measure the output of the peak detector using the ADC of the microcontroller. The distance from the transmitter is proportional to the voltage measured.

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Project 2 Description

# Robot Tracking Logic

- If (d1>d) move motor 1 back.
- If (d2>d) move motor 2 back.
- If (d1<d) move motor 1 forward.
- If (d2<d) move motor 2 forward.
- d is preset after reset, but it can be changed by receiving a command from the remote if you wish.




# Receiving Commands From the Modulated Magnetic Field

- Connect one of the received signals to a voltage comparator to convert it to a logic signal.
- Assume “field present” is logic one.
- Connect the output of the comparator (don’t forget the pull-up resistor) to the receive pin of UART1. (More on this later)

# Sending Commands From the Remote to the Robot

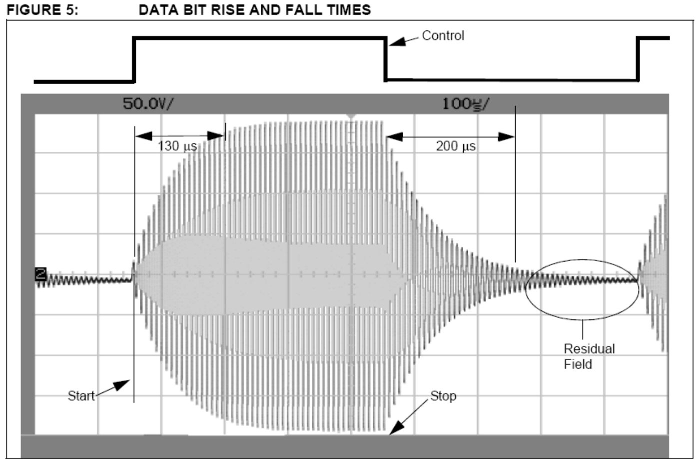
- Check application note from Microchip. It describes On-Off Keying for data transmission:
  http://ww1.microchip.com/downloads/en/AppNotes/00232B.pdf
- A minimum of four commands required:
  - **Move Left. When the user pushes a push button, the robot must turn left.**
  - **Move Right. When the user pushes a push button, the robot must turn right.**
  - **Move Forward. When the user pushes a push button, the robot must move forward.**
  - **Move Backward. When the user pushes a push button, the robot must move backward.**




# Data Bit Rise and Fall Times

From Microchip's application note AN232 “Low-Frequency Magnetic Transmitter Design”

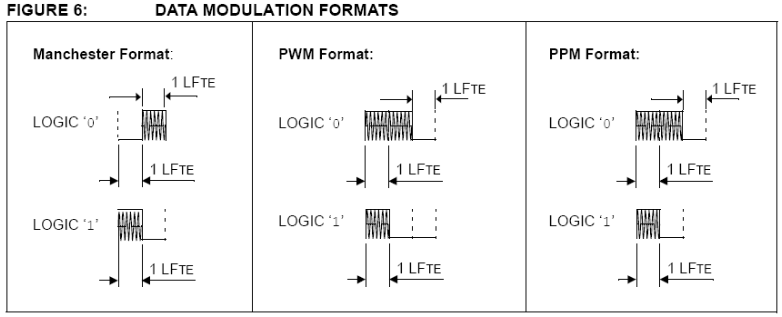
**FIGURE 5: DATA BIT RISE AND FALL TIMES**



# Data Modulation Formats

From Microchip's application note AN232 "Low-Frequency Magnetic Transmitter Design"

FIGURE 6: DATA MODULATION FORMATS




Since you'll need to transmit only a few data bits, it is not a problem to assume 'field present' equal 'logic one' and 'field not present' equal 'logic zero'. The baud rate has to be very low.





# Robot Construction

| Part # | Description |
|---|---|
| 2 x Solarbotics GM4 | Gear Motor 4 - Clear Servo |
| 2 x 3D printed wheels | 6.7cm wheels (pair) |
| Tamiya 70144 | Ball Caster |
| 4 x AA | Battery holder |
| Switch | DPDT. Can be used to switch two different power sources. |
| 1 x 9V cable | 9V battery clip |
| Folded chassis | Aluminum box with holes! |

# Using MOSFETs

- MOSFETs (Metal Oxide Semiconductor Field Effect Transistors) are voltage controlled devices.
- There are many kinds of MOSFETs. The ones often used are channel enhancement PMOS and NMOS.
- The two parameters used to design with MOSFETs (as switches) are the Threshold Voltage $V_t$, and the resistance between drain and source $R_{DS}$.

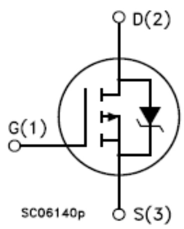




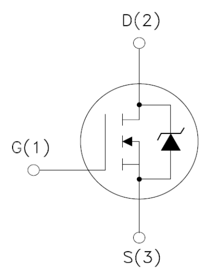
# MOSFET operation modes

- As with the BJTs, there are three operating modes:
  - Cutoff: $V_{GS}<V_t$
  - Triode: $V_{DS}<(V_{GS}-V_t)$
  - Saturation: $V_{DS}\geq(V_{GS}-V_t)$
- To use the MOSFET as switch, operate it in the cutoff and triode modes. If you operate it in saturation it will get really-really hot!

# FQU8P10 and FQU13N06 MOSFETS (or Equivalent)




**FQU8P10**




**FQU13N06**

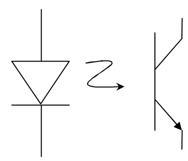
**WARNING: Extremely sensitive to electrostatic discharges. Very easy to damage!**




# Optocouplers

- An optocoupler is a combination of a light source and a photosensitive element
- You can use an optocoupler when you want to isolate high or very high voltages, inductive circuits, or "noisy" circuits from the microcomputer system.
- The typical optocoupler consists of an infrared LED and a NPN BJT.
- The BJT usually doesn't have a base pin! Instead it is the light from the LED what is used to saturate the transistor.

# Designing with Optocouplers

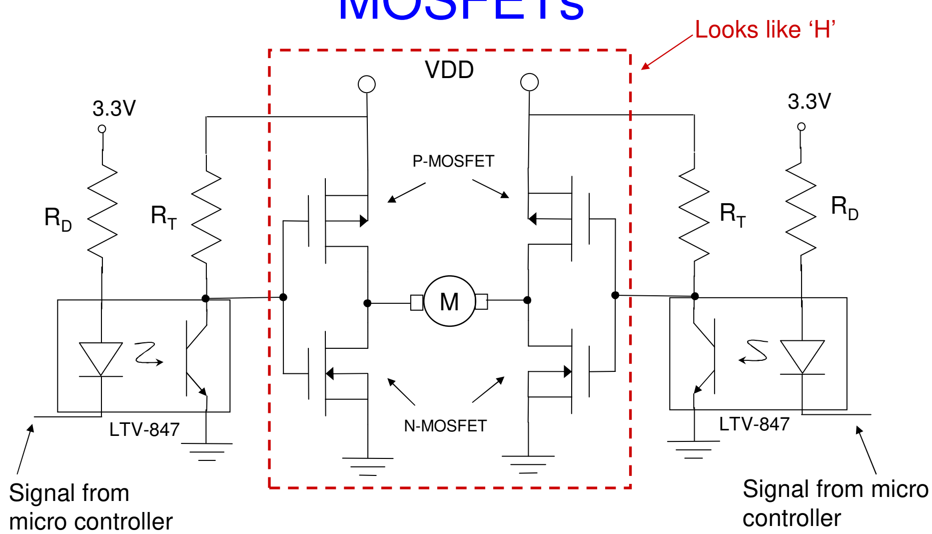


Some optocouplers include a base pin!

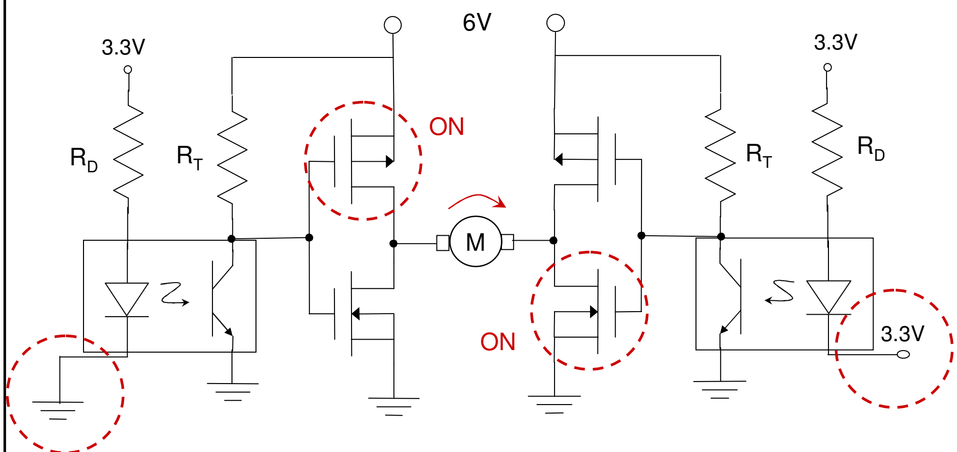
- When designing with optocouplers you take into consideration the following parameters:
  - The current transfer ratio (CTR) is a parameter similar to the DC current amplification ratio of a transistor (β) and is expressed as a percentage indicating the ratio of the output current ($I_C$) to the input current ($I_F$).
    $CTR(\%)=(I_C/I_F) \times 100$
  - The Diode forward voltage (1.2 to 1.4V).
  - The maximum diode forward current (around 50mA max).
  - The BJT saturation voltage (0.1 to 0.4V).
  - The voltage isolation between the diode and the transistors (a few hundred volts to thousands of volts)




# H-Bridge with Optocouplers and MOSFETs



# H-Bridge with Optocouplers and MOSFETs CW Rotation

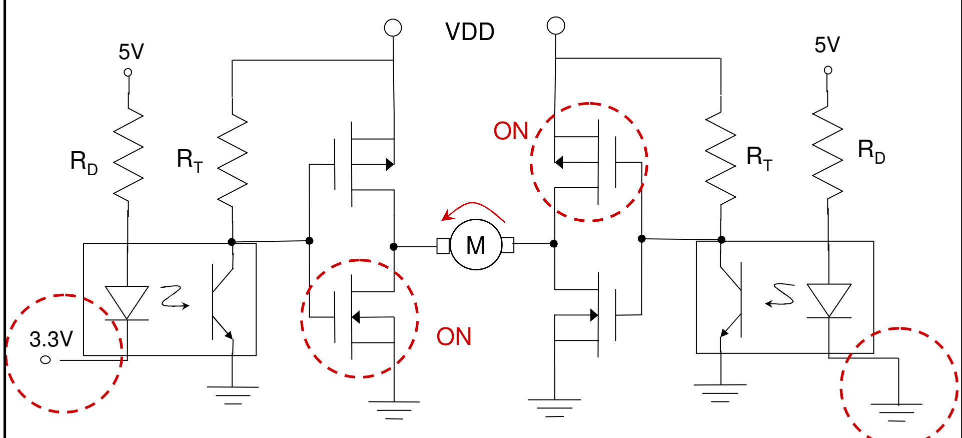




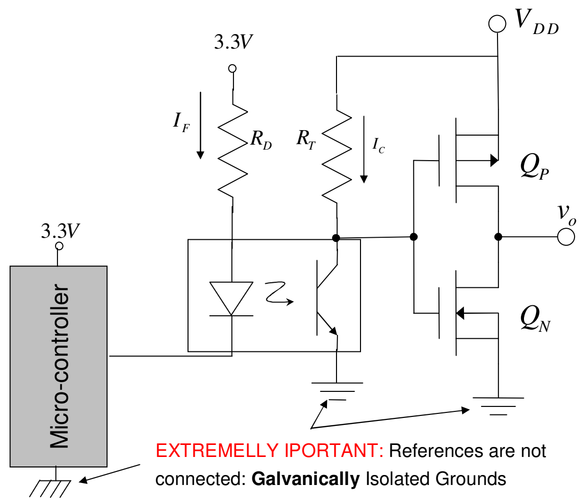




# H-Bridge with Optocouplers and MOSFETs CCW Rotation



# H-Bridge with Optocouplers and MOSFETs: Calculations.




Assume $R_T$=10kΩ, $V_{DD}$=6V, $V_{CE(sat)}$=0.2, LED forward voltage=1.2V, CTR=50%. Find $R_D$!

$$I_C = \frac{6V - 0.2V}{10k\Omega} = 0.58mA$$

$$CTR = \frac{I_C}{I_F} \times 100$$

$$I_F = \frac{I_C \times 100}{CTR} = \frac{0.58mA \times 100}{50} = 1.16mA$$

$$R_D < \frac{3.3V - 1.2V}{1.16mA} = 1.81k\Omega$$

Only half of the H-bridge shown. The other half is identical.




# LTV-847/LTV-846 Optocoupler

- CTR=50%
- Diode forward voltage=1.4 max.
- Maximum diode forward current is 50mA
- The BJT saturation voltage is less than 0.12V!
- Voltage isolation 5000$V_{RMS}$

# C programmed.

- Both the robot and the remote must be programmed using the C programming language.
- You may 'inline' small portions of assembly code, but the bulk of your code must be C.




# Battery powered.

- Your project must be battery powered. This includes the electronics and motors of both the transmitter and receiver
- A couple 9 volt battery strap and a 4 x AA battery holder are included in the parts kit for this project.
- You can use any kind of batteries you want, provided that you acquire the batteries and the holders yourself.
- WARNING: batteries are neither included in the parts kits nor they will be provided in the lab. You must buy your own batteries.
- TIP: Brand name batteries have lower internal resistance, but they are more expensive.

WARNING!

HIGH VOLTAGE CIRCUIT. DO NOT TOUCH. HANDLE WITH EXTREME CARE.