



University of British Columbia
Electrical and Computer Engineering
ELEC291/ELEC292

Project 2: Magnetic Field Controlled Robot.

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Project 2 Description

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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.).

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Microcontrollers

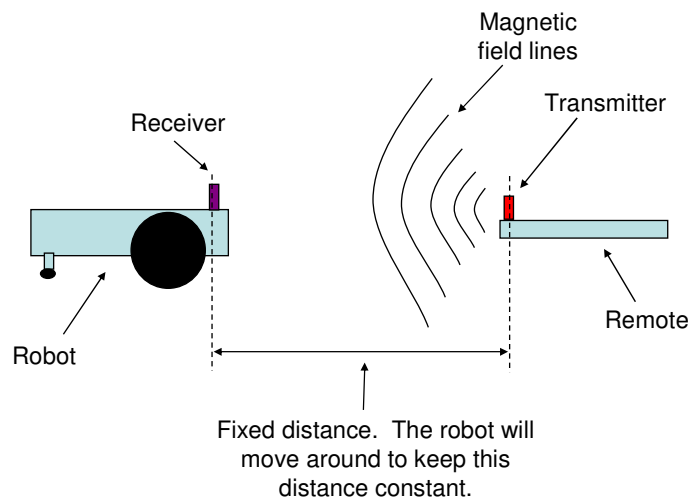
1. The two microcontroller systems **MUST** be from different families. Some microcontrollers are provided in the project #2 kit: MSP430G2553, PIC32MX130, ATmega328P, LPC824, and STM32L051. You have from previous kits: EFM8LB12 and AT89LP51RC2.
2. One **valid** combination: the transmitter using the EFM8LB12 (8051 family) and the robot using the PIC32MX130 microcontroller (MIPS family).
3. One **invalid** 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.

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Magnetic Field Controlled Robot

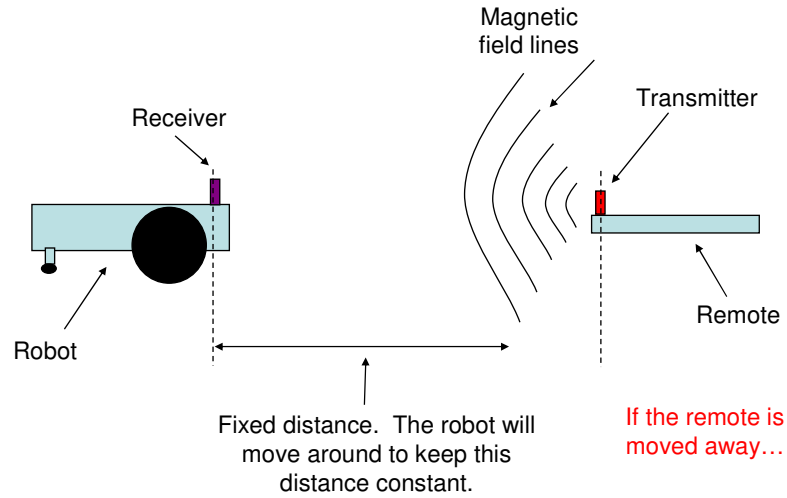


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Magnetic Field Controlled Robot

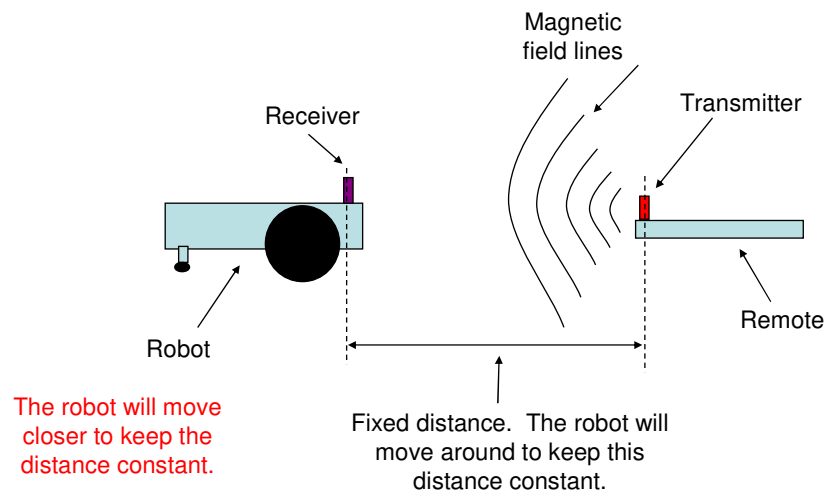


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Magnetic Field Controlled Robot

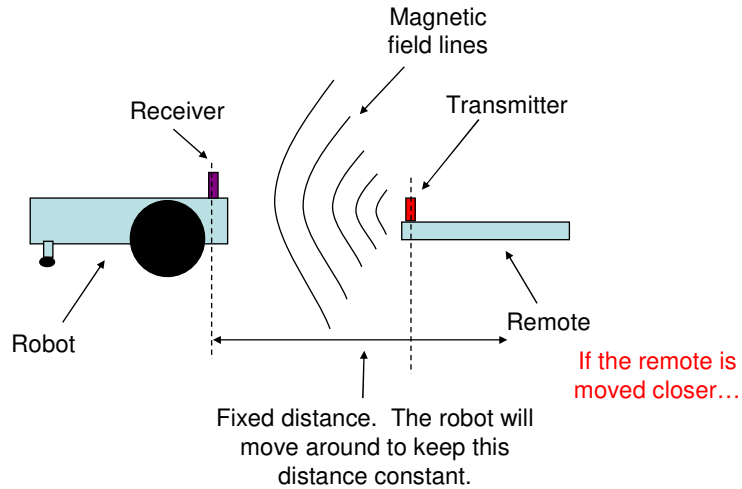


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Magnetic Field Controlled Robot

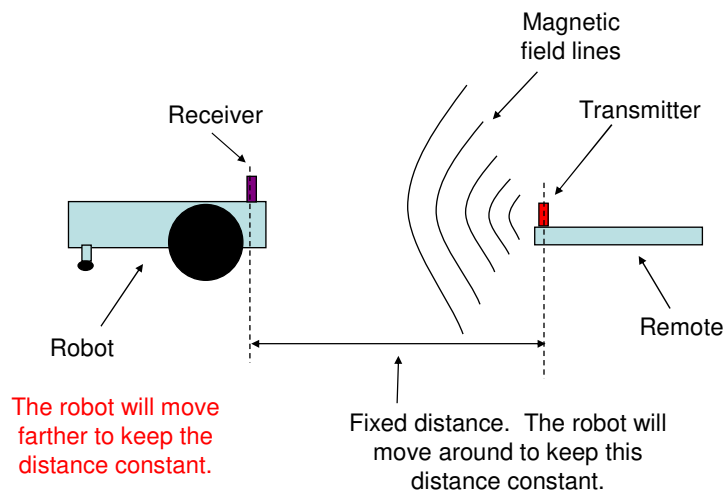


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Transmitter

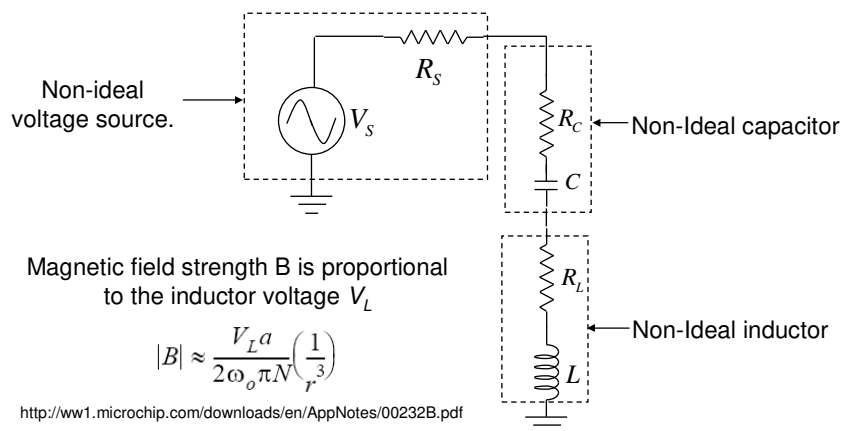
- It is a series RLC circuit you should know from ELEC202.
- The inductor (L) is provided in the robot kit. You can use any inductor you want!
- For the capacitor (C) you can use the capacitors you already have, but they may not work very well. Optionally you can buy a much better capacitor in local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

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Simplified RLC Transmitter Circuit

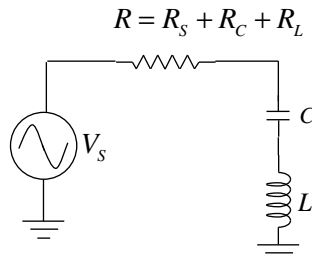


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Simplified RLC Transmitter Circuit



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

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

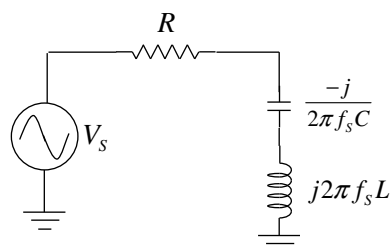
Other factors affect the magnitude of V_L . Use phasor analysis!

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Simplified RLC Transmitter Circuit



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

$$i = \frac{V_s}{R - \frac{j}{2\pi f_s C} + j2\pi f_s L} = \frac{V_s}{R}$$

At the tuned frequency this two values are equal!

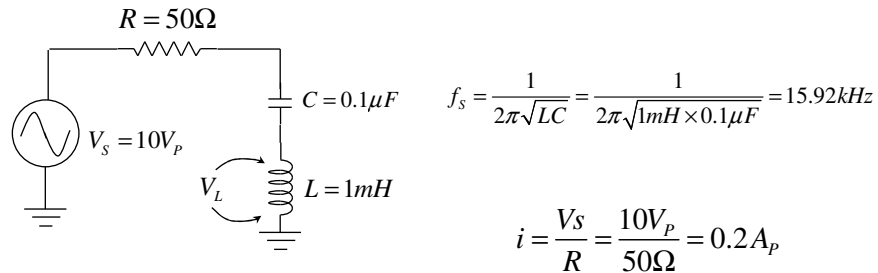
$$V_L = \frac{jV_s 2\pi f_s L}{R}$$

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Simplified RLC Transmitter Circuit test using function generator.



$$V_L = j \times 0.2A_p \times 2\pi \times 15.92kHz \times 1mH = 20V_p$$

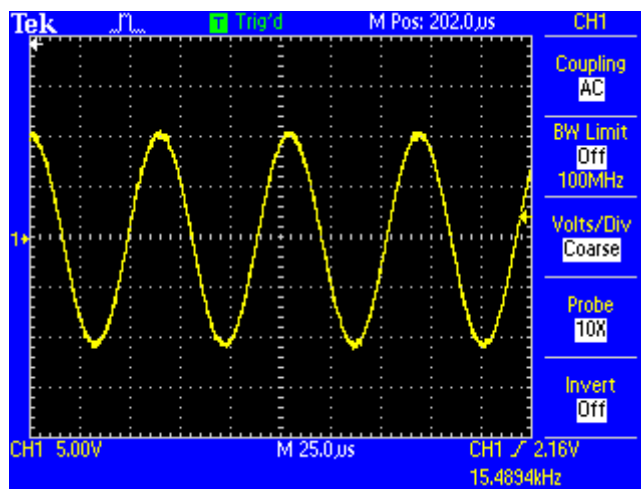
Not good enough. You'll need about 150 V_p!

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V_s Using a Function Generator

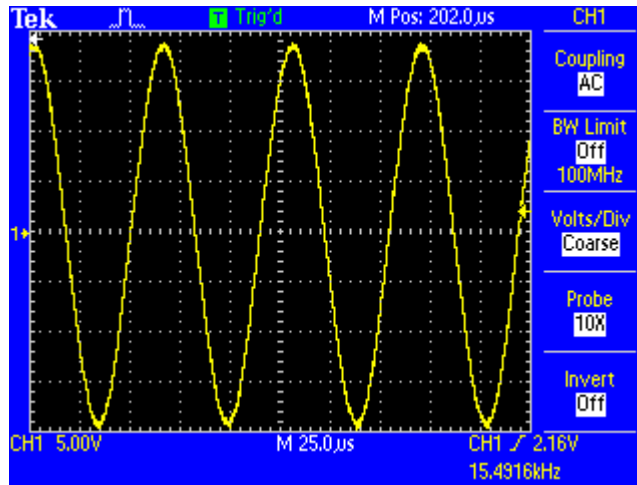


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V_L From the Circuit Above



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Maximizing V_L

- Increase V_S .
 - Con: Large source voltages are difficult to handle. Potentially dangerous.
- ~~Increase f_s .~~
 - Con: It won't work because f_s is also in the denominator of the magnetic field strength equation $|B| \approx \frac{V_L a}{2\omega_0 \pi N} \left(\frac{1}{r}\right)^3$
- ~~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 !

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V_S

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

$$x(t) = \frac{4}{\pi} \sum_{k=1}^{\infty} \frac{\sin(2\pi(2k-1)ft)}{2k-1} = \frac{4}{\pi} \left(\sin(2\pi ft) + \frac{1}{3} \sin(6\pi ft) + \frac{1}{5} \sin(10\pi ft) + \dots \right)$$

Fundamental
3rd harmonic
5th harmonic

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

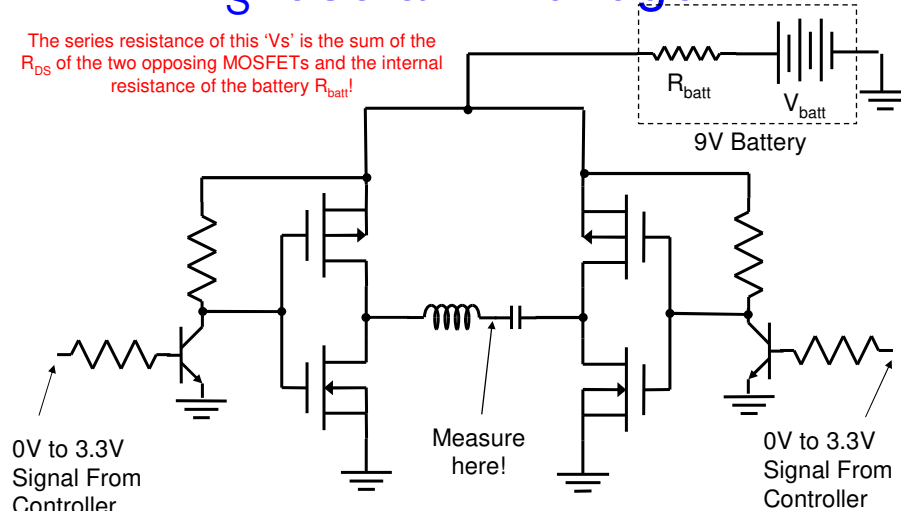
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V_S : use an H-bridge!

The series resistance of this ' V_S ' 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.

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Finding the Tuned Frequency

- At the tuned frequency the output voltage as indicated in the previous slide is at its 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.

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- 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 a 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 to 10X attenuation.

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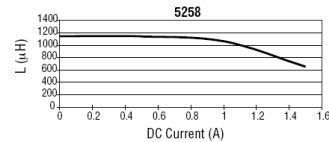
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The Inductor

- 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



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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 ONE to each team.

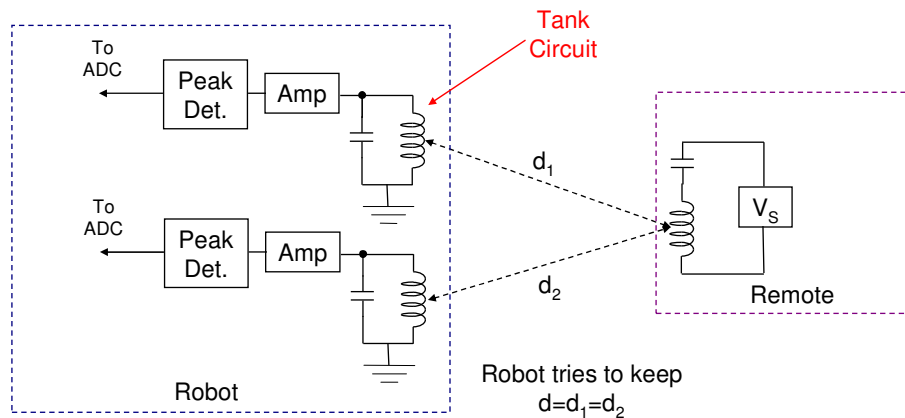
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The Receiver

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



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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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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.

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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)

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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.

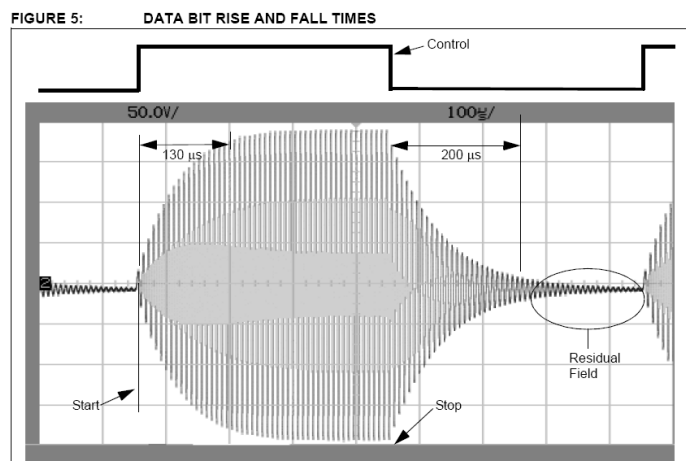
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Data Bit Rise and Fall Times

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



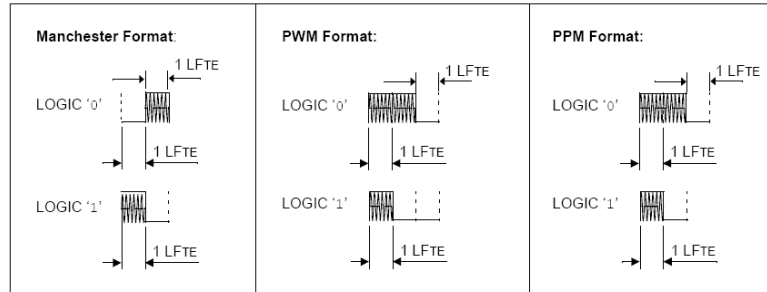
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Data Modulation Formats

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.

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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!

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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} .

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MOSFET operation modes

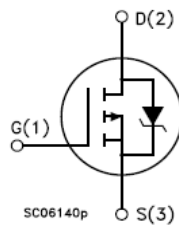
- As with the BJTs, there are three operating modes:
 - Cutoff: $V_{GS} < V_t$
 - Triode: $V_{DS} < (V_{GS} - V_t)$
 - Saturation: $V_{DS} \geq (V_{GS} - V_t)$
- To use the MOSFET as switch, operate it in the cutoff and triode modes. If you operate it in saturation it will get really-really hot!

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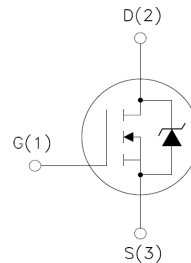
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FQU8P10 and FQU13N06 MOSFETS (or Equivalent)



FQU8P10



FQU13N06

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

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Optocouplers

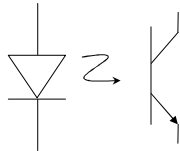
- An optocoupler is a combination of a light source and a photosensitive element
- You can use an optocoupler when you want to isolate high or very high voltages, inductive circuits, or “noisy” circuits from the microcomputer system.
- The typical optocoupler consists of an infrared LED and a NPN BJT.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

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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).

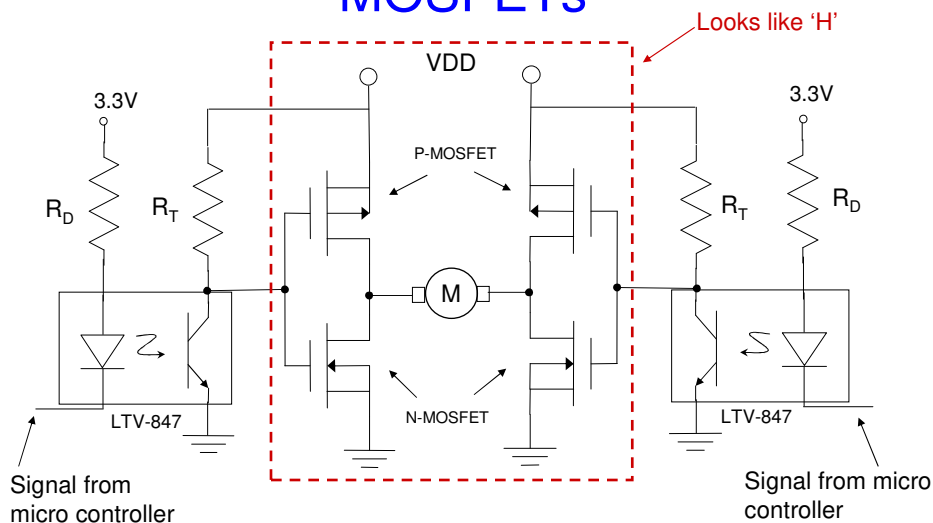
$$CTR(\%) = (I_C / I_F) \times 100$$
 - The Diode forward voltage (1.2 to 1.4V).
 - The maximum diode forward current (around 50mA max).
 - The BJT saturation voltage (0.1 to 0.4V).
 - The voltage isolation between the diode and the transistors (a few hundred volts to thousands of volts)

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H-Bridge with Optocouplers and MOSFETs

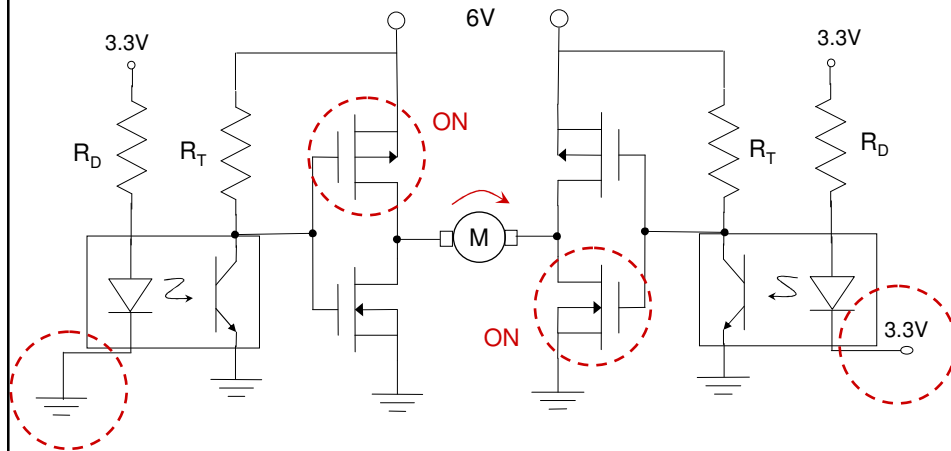


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H-Bridge with Optocouplers and MOSFETs CW Rotation

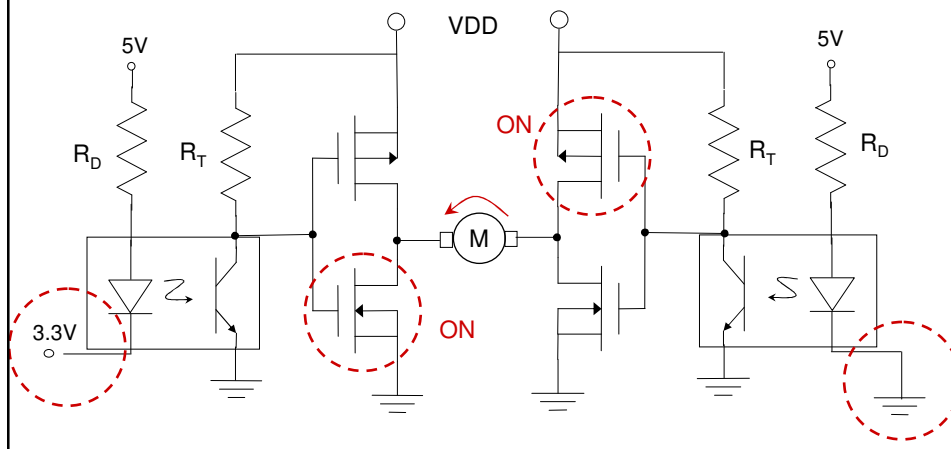


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H-Bridge with Optocouplers and MOSFETs CCW Rotation

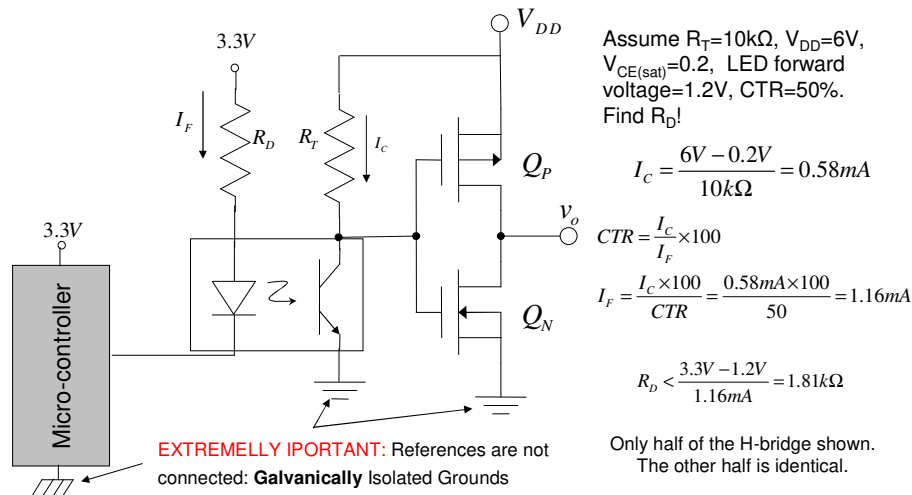


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H-Bridge with Optocouplers and MOSFETs: Calculations.



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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 5000V_{RMS}

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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.

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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.

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



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