University of British Columbia
Electrical and Computer Engineering
ELEC291/ELEC292

Project 2: Magnetic Field Controlled Robot.

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Requirements

- Microcontroller Systems (two needed!):
  - One for the robot (the receiver). Receives commands and moves the robot around.
  - One for the Transmitter . It generates the magnetic field and sends commands to the Robot.
- Microcontroller Systems must be from different families.
- Programmed in C.
- The robot must be battery powered**.**
- Discrete MOSFET drivers.
- Commands transmitted to the robot from the transmitter:
  - **Stop.**
  - **Turn left.**
  - **Turn right.**
  - **Move Forward.**
  - **Move Backward.**
- Minimum range of 100 cm.
- **Task:** move three objects (200 cm^3) from 'send' area to 'receive' area. Two 20cm circles 100cm apart.
- **Communication between robot and transmitter:** only magnetic field allowed. No Bluetooth, WIFI, radios, etc.

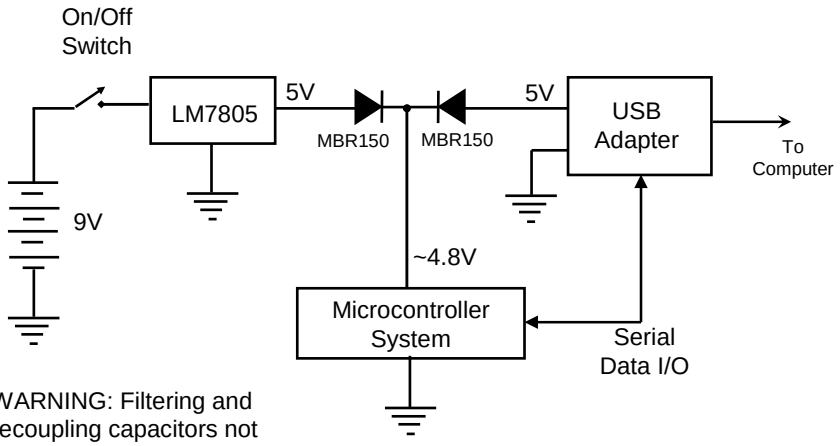
Getting Started with a New Microcontroller System

1. Obtain/assemble the hardware. Also documentation: datasheets & manuals.
2. Obtain/install the development environment. Also documentation like manuals.
3. Obtain/install a means of putting the 'firmware' in the hardware. May require additional hardware tools and software.
4. Settle a workflow. Also: examples, application notes, and forums.

Getting Started with a New Microcontroller System

- In this course is not too difficult. Instructions provided for:
  - STM32F052: LQFP32. 64k flash. ST Microelectronics. ARM architecture.
  - LPC824: TSOP 20. 32k flash. NXP. ARM architecture.
  - PIC32MX130: DIP-28. 64k flash. Microchip. MIPS architecture.
  - ATmega328p: DIP-28. 32k flash. Atmel/Microchip. AVR architecture.
  - MSP430G2553. DIP-20. 16k flash. Texas Instruments. MSP430 architecture.
  - AT89LP51RC2. DIP-40. 32k flash. Atmel/Microchip. 8051 architecture. Used in first half of the course. Extra 'Makefile' examples in Connect.
  - EFM8 board with EFM8LB1. 64k flash. LQFP32. Silicon Labs. 8051 architecture. Used in second half of the course. Extra 'Makefile' examples in Connect.

Using Batteries to Power the Microcontroller System

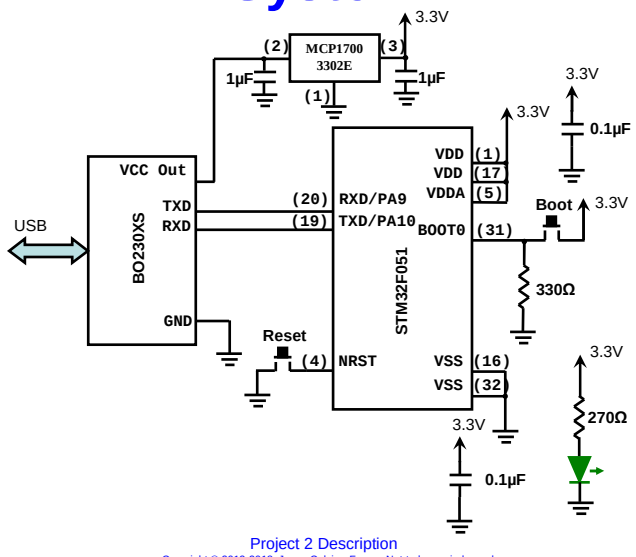


WARNING: Filtering and decoupling capacitors not shown. Check LM7805 datasheet!

The STM32F051 Microcontroller System

1. Hardware: Bare IC + Adapter in breadboard.
2. Development environment: GCC for ARM.
3. Flash Loader: Port of official FLASHER-STM32 from ST Microelectronics via BO23XS board.
4. Workflow: via Makefiles in CrossIDE. Examples in Connect.

The STM32F051 Microcontroller System

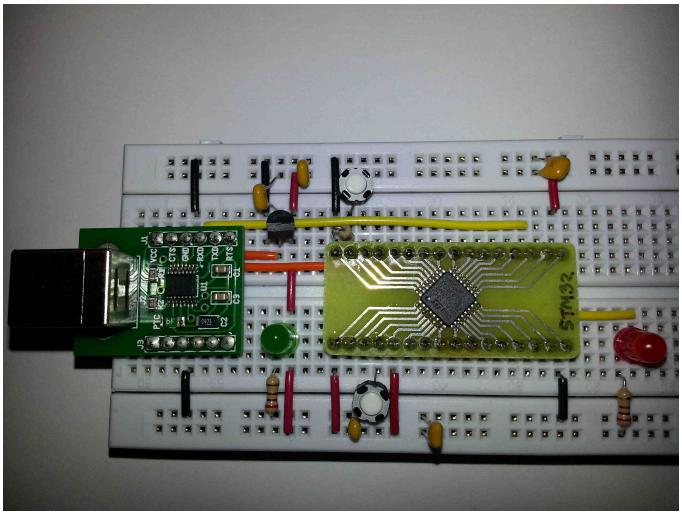


The STM32F051 Microcontroller System

Qty	Supplier's#	Man's #	Description	Price
2	BC1148CT-ND	K104Z15Y5VE5TL2	CAP CER 0.1UF 25V Y5V RADIAL	0.54
2	BC1157CT-ND	K105Z20Y5VE5TH5	CAP CER 1UF 25V Y5V RADIAL	0.94
2	270QBK-ND	CFR-25JB-52-270R	RES 270 OHM 1/4W 5% AXIAL	0.30
1	330QBK-ND	CFR-25JB-52-330R	RES 330 OHM 1/4W 5% AXIAL	0.15
1	67-1102-ND	SSL-LX5093HD	LED RED DIFF 5MM ROUND T/H	0.55
1	67-1108-ND	SSL-LX5093LGD	LED GRN DIFF 5MM ROUND T/H	0.62
1	MCP1700-3302E/TO-ND	MCP1700-3302E/TO	IC REG LDO 3.3V 0.25A TO92-3	0.57
1	497-13626-ND	STM32F051K8T6	IC MCU 32BIT 64KB FLASH 32LQFP	4.14
0.33	1528-1065-ND	1163	SMT ADAPTERS 3 PACK 32QFN/TQFP	2.82
2	A26509-16-ND	4-103741-0-16	CONN HEADR BRKWAY .100 16POS STR	3.12
2	P8070SCT-ND	EVQ-11A04M	SWITCH TACTILE SPST-NO 0.02A 15V	0.70

Total 14.45

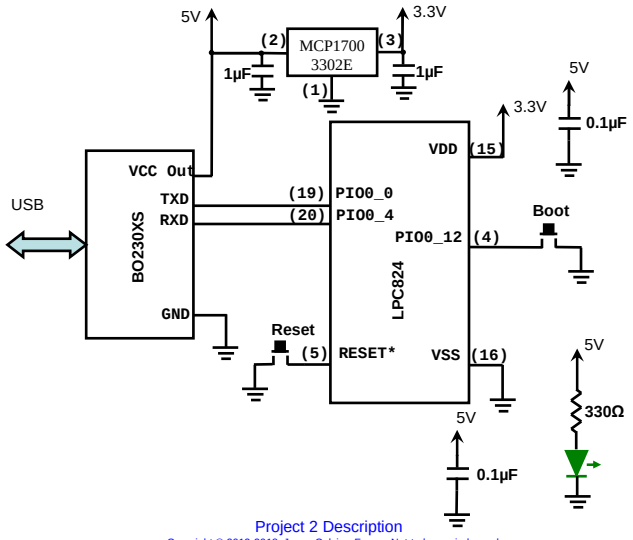
The STM32F051 Microcontroller System



The LPC824 Microcontroller System

1. Hardware: Bare IC + Adapter in breadboard.
2. Development environment: GCC for ARM.
3. Flash Loader: Port of lpc21isp via BO23XS board.
4. Workflow: via makefiles in CrossIDE. Examples in Connect.

The LPC824 Microcontroller System

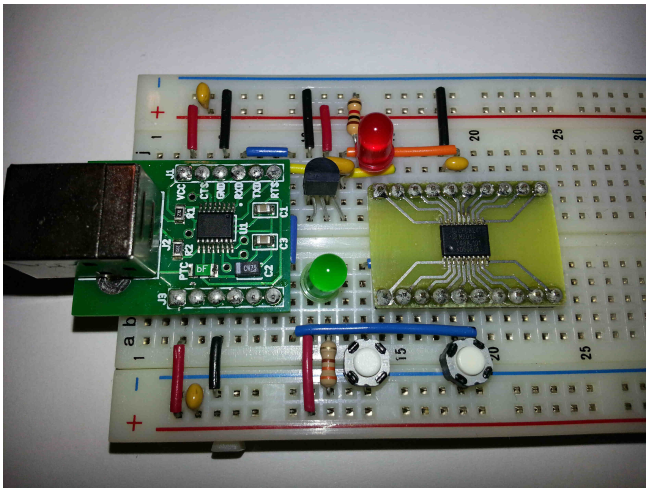


The LPC824 Microcontroller System

Qty	Supplier's#	Man's #	Description	Price
2	BC1148CT-ND	K104Z15Y5VE5TL2	CAP CER 0.1UF 25V Y5V RADIAL	0.54
2	BC1157CT-ND	K105Z20Y5VE5TH5	CAP CER 1UF 25V Y5V RADIAL	0.94
1	1.0QBK-ND	CFR-25JB-52-1R	RES 1 OHM 1/4W 5% AXIAL	0.15
1	330QBK-ND	CFR-25JB-52-330R	RES 330 OHM 1/4W 5% AXIAL	0.15
1	67-1102-ND	SSL-LX5093HD	LED RED DIFF 5MM ROUND T/H	0.55
1	67-1108-ND	SSL-LX5093LGD	LED GRN DIFF 5MM ROUND T/H	0.62
1	MCP1700-3302E/TO-ND	MCP1700-3302E/TO	IC REG LDO 3.3V 0.25A TO92-3	0.57
1	568-11619-1-ND	LPC824M201JDH20J	IC MCU 32BIT 32KB FLASH 20TSSOP	2.74
0.33	1528-1066-ND	1206	SMT ADAPTERS 3 PACK 20SOIC/TSSOP	2.13
2	A26509-10-ND	4-103741-0-10	CONN HEADR BRKWAY .100 10POS STR	2.32
2	P8070SCT-ND	EVQ-11A04M	SWITCH TACTILE SPST-NO 0.02A 15V	0.70

Total 10.71

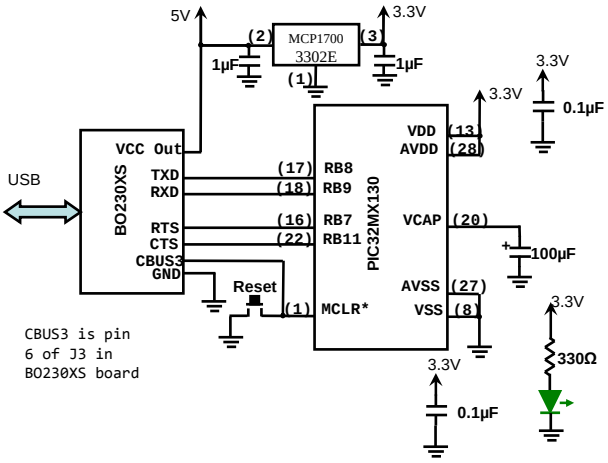
The LPC824 Microcontroller System



The PIC32 Microcontroller System

1. Hardware: Bare IC in breadboard.
2. Development environment: XC32 from Microchip. (Derived from GCC but…)
3. Flash Loader: Pro32 via BO230XS board by yours truly.
4. Workflow: via Makefiles in CrossIDE. Examples in Connect.

The PIC32 Microcontroller System

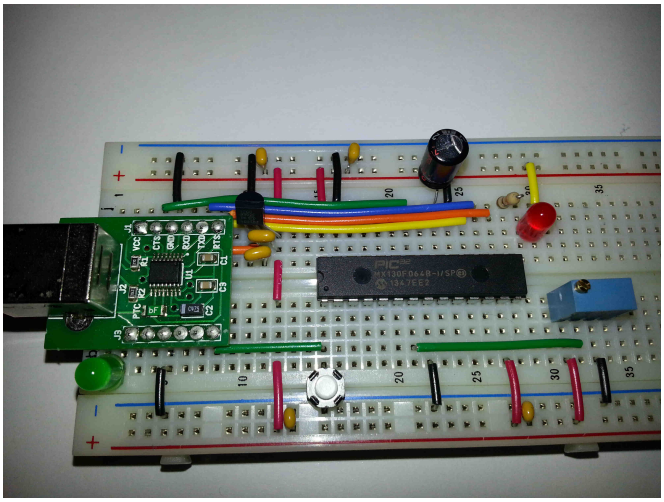


The PIC32 Microcontroller System

Qty	Supplier's#	Man's #	Description	Price
2	**BC1148CT-ND**	K104Z15Y5VE5TL2	CAP CER 0.1UF 25V Y5V RADIAL	0.54
2	BC1157CT-ND	K105Z20Y5VE5TH5	CAP CER 1UF 25V Y5V RADIAL	0.94
2	330QBK-ND	CFR-25JB-52-330R	RES 330 OHM 1/4W 5% AXIAL	0.30
1	67-1102-ND	SSL-LX5093HD	LED RED DIFF 5MM ROUND T/H	0.55
1	67-1108-ND	SSL-LX5093LGD	LED GRN DIFF 5MM ROUND T/H	0.62
1	MCP1700-3302E/TO-ND	MCP1700-3302E/TO	IC REG LDO 3.3V 0.25A TO92-3	0.57
1	PIC32MX130F064B-I/SP-ND	PIC32MX130F064B-I/SP	IC MCU 32BIT 64KB FLASH 28SDIP	4.23
1	493-1548-ND	UHE1E101MED	CAP ALUM 100UF 20% 25V RADIAL	0.41
2	P8070SCT-ND	EVQ-11A04M	SWITCH TACTILE SPST-NO 0.02A 15V	0.70

Total 8.86

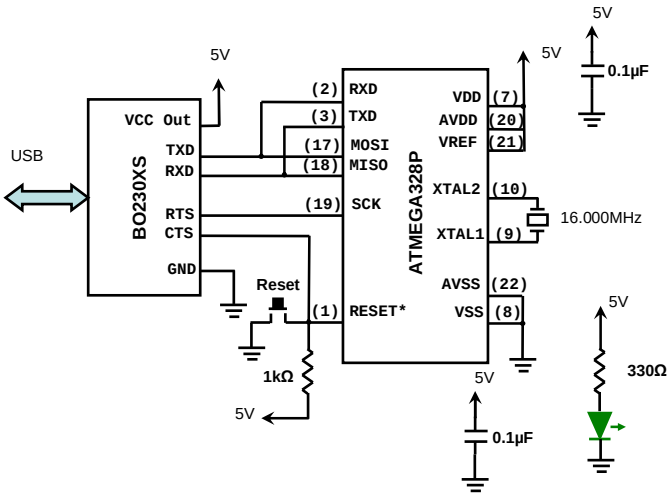
The PIC32 Microcontroller System



The AVR Microcontroller System

1. Hardware: Bare IC in breadboard.
2. Development environment: Atmel AVR 8-bit Toolchain for Windows.
3. Flash Loader: spi_atmega328 via BO230XS board by yours truly.
4. Workflow: via Makefiles in CrossIDE. Examples in Connect.

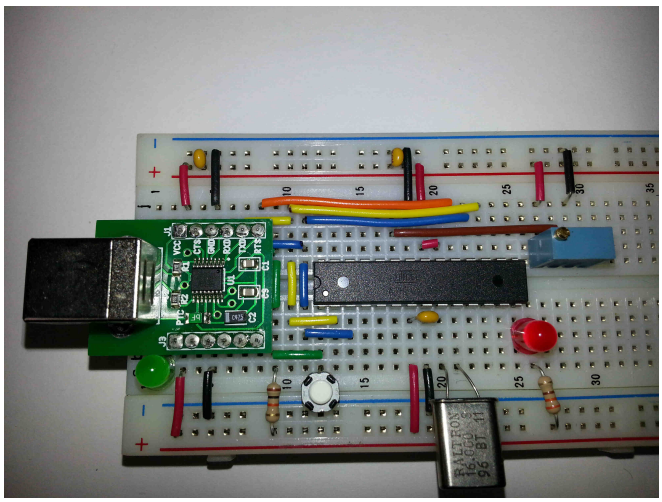
The AVR Microcontroller System



The AVR Microcontroller System

Qty	Supplier's#	Man's #	Description	Price
3	BC1148CT-ND	K104Z15Y5VE5TL2	CAP CER 0.1UF 25V Y5V RADIAL	0.81
1	1.0KQBK-ND	CFR-25JB-52-1K	RES 1K OHM 1/4W 5% AXIAL	0.15
2	330QBK-ND	CFR-25JB-52-330R	RES 330 OHM 1/4W 5% AXIAL	0.30
1	67-1102-ND	SSL-LX5093HD	LED RED DIFF 5MM ROUND T/H	0.55
1	67-1108-ND	SSL-LX5093LGD	LED GRN DIFF 5MM ROUND T/H	0.62
1	CTX1085-ND	ATS16B	CRYSTAL 16.0000MHZ 18PF T/H	0.54
1	ATMEGA328P-PU-ND	ATMEGA328P-PU	IC MCU 8BIT 32KB FLASH 28DIP	3.24
1	P8070SCT-ND	EVQ-11A04M	SWITCH TACTILE SPST-NO 0.02A 15V	0.35
			Total	6.56

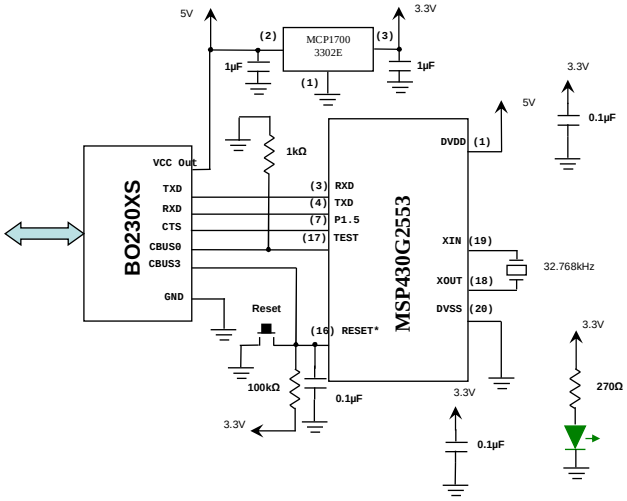
The AVR Microcontroller System



The MSP430 Microcontroller System

1. Hardware: Bare IC + Adapter in breadboard.
2. Development environment: GCC for MSP430.
3. Flash Loader: MSP430_prog via BO23XS board by yours truly.
4. Workflow: via makefiles in CrossIDE. Examples in Connect.

The MSP430 Microcontroller System

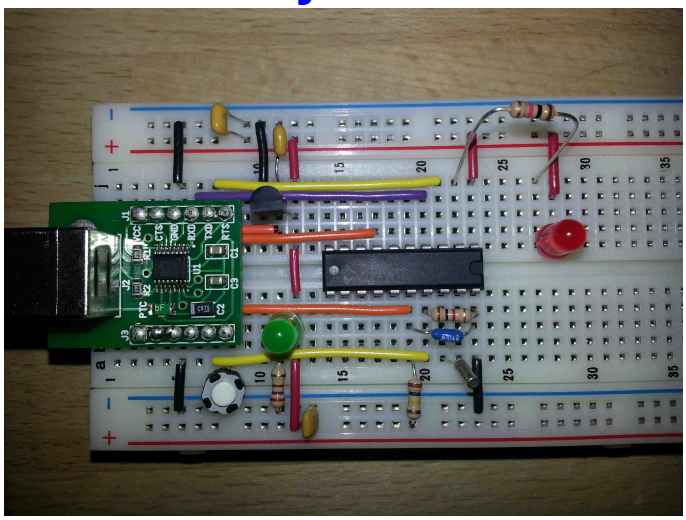


The MSP430 Microcontroller System

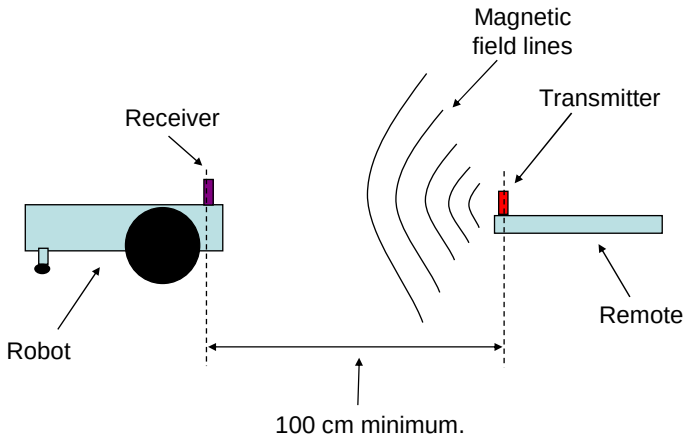
Quantity	Digi-Key Part #	Description	
3	BC1148CT-ND	0.1uF ceramic capacitors	0.73
2	BC1157CT-ND	1uF ceramic capacitor	0.90
2	270QBK-ND	270Ω resistor	0.30
1	1.0KQBK-ND	1kΩ resistor	0.15
1	100KQBK-ND	100kΩ resistor	0.15
1	MCP1700-3302E/TO-ND	IC REG LINEAR 3.3V 250MA TO92-3	0.57
1	67-1108-ND	LED 5MM GREEN	0.59
1	300-8842-ND	CRYSTAL 32.7680KHZ 7PF T/H	0.35
1	296-28429-5-ND	MSP430G2553	3.93
1	P8070SCT-ND	Push button switch	0.34

$8.01

The MSP430 Microcontroller System



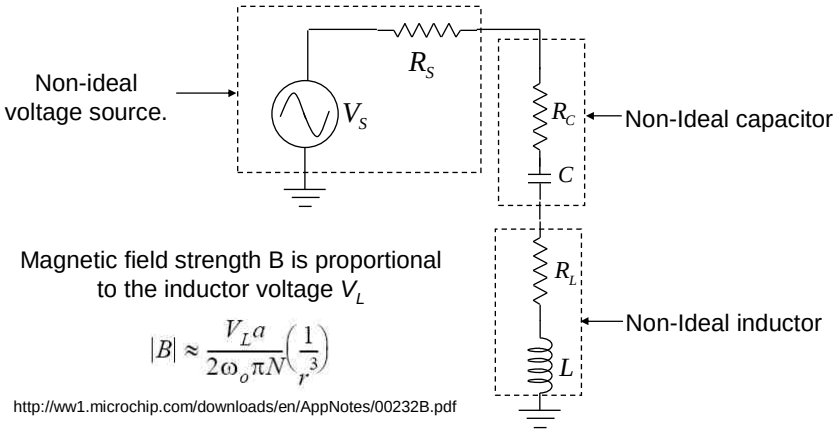
Magnetic Field Controlled Robot



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



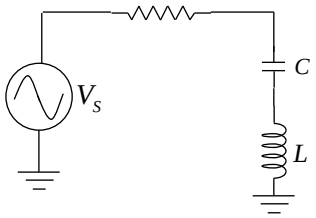
Magnetic field strength B is proportional to the inductor voltage V_L

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

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!

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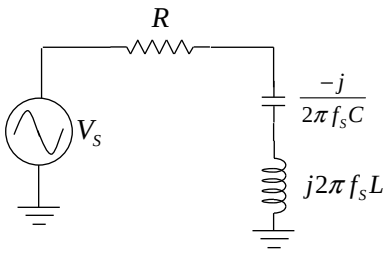
Simplified RLC Transmitter Circuit



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

At the tuned frequency this two values are equal!

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

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

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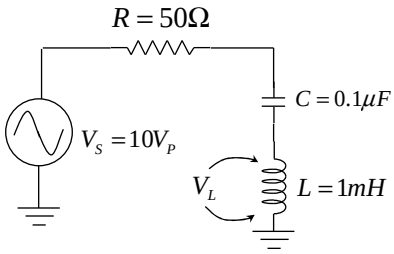
Simplified RLC Transmitter Circuit test using function generator.



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

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

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

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

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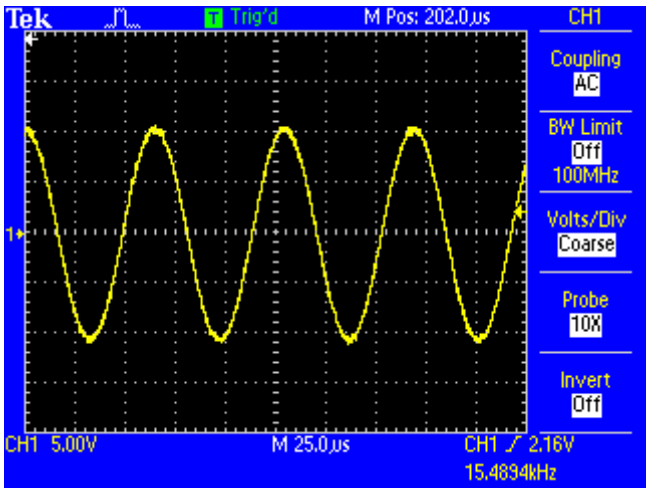
V_S Using a Function Generator



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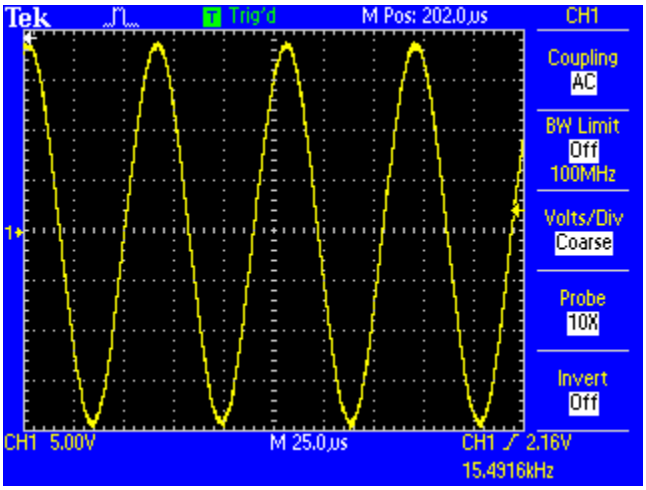
V_L From the Circuit Above



Maximizing V_L

- Increase V_S.
  - Con: Large source voltages are difficult to handle. Potentially dangerous.
- ~~Increase f_S.~~
  - Con: It ~~won't~~ work because f_s is in the denominator of the magnetic field strength equation.
- ~~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!

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

V_S

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

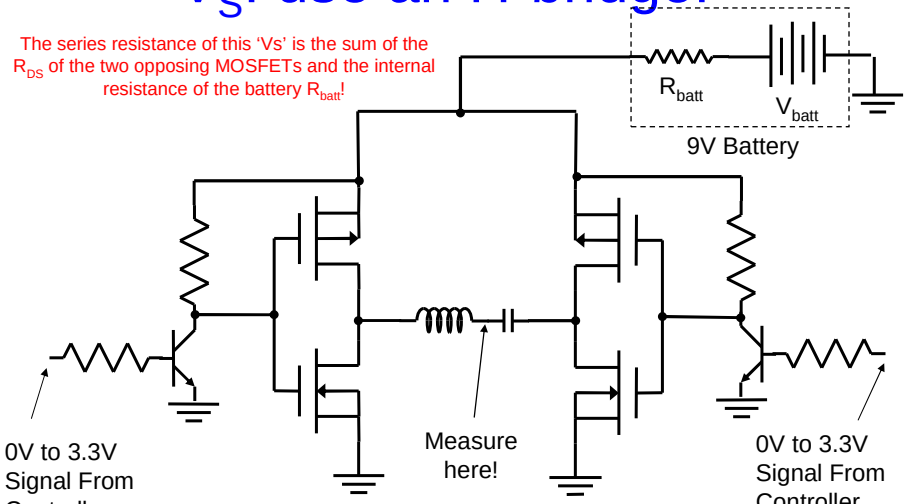
$$x(t) = \frac{4}{\pi}\sum_{k=1}^{\infty}\frac{\sin(2\pi(2k-1)ft)}{2k-1} = \frac{4}{\pi}\left(\sin(2\pi ft) + \frac{1}{3}\sin(6\pi ft) + \frac{1}{5}\sin(10\pi ft) + ...\right)$$

Fundamental — 3rd harmonic — 5th harmonic

Bonus: The amplitude of the fundamental is 4/π=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 BJTs 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 see 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.c' available in connect to find the tuned frequency.

WARNING!

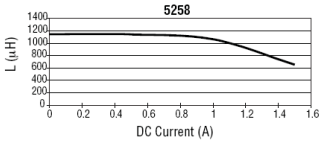
- If you use a low resistance source, like the H-bridge from the previous slides, the peak voltage at both the inductor and capacitor may increase to hundreds of volts:
  - If you touch the circuit you will get shocked! **DO NOT TOUCH THE INDUCTOR/CAPACITOR** when the circuit is on. Safety tip: use an 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.

The Inductor

- DigiKey part number M8275-ND

Don't drop the inductor. The ferrite core may break!

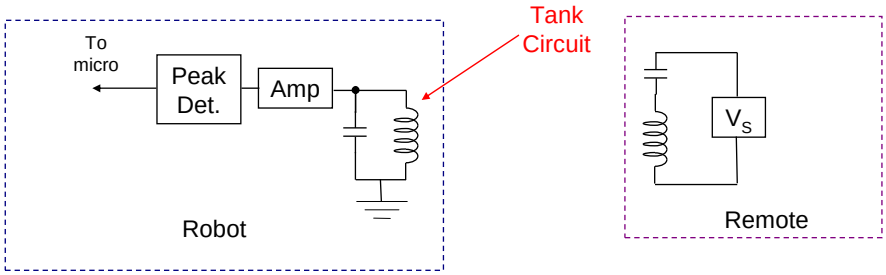
Type	Wirewound
Material - Core	Ferrite
Inductance	1mH
Tolerance	±20%
Current Rating	1A
DC Resistance	0.55 Ohms



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, Main, or Lee's and buy a good capacitor!

The Receiver



Receiving/Transmit Commands Using the Magnetic Field

- Using Extra Uart (a form of AM):
  - For example: 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)
- PWM of magnetic field:
  - Different pulse widths correspond to different commands.
- FM of magnetic field:
  - Different, but close frequencies correspond to different commands.

Robot Construction

Part #	Description
Solarbotics GM4	Gear Motor 4 - Clear Servo
Lynxmotion Servo Wheel	2.63" x 0.35" (pair) wheels
Tamiya 70144	Ball Caster
4 x AA	Battery holder
1 x 9V cable	9V battery clip
Unfolded chassis	Aluminum chassis made using the water jet cutter.

Fitting the Wheels to the Motors

Question:

"*We're finally assembling our rover and the wheels seem to not have the same spline pattern as the motor shaft. I'd rather not force these to mate. Is this unusual? Can you suggest a solution?*"

Answer:

The wheels pressure fit into the motor shafts. The wheels are flexible so they will expand a bit making an excellent and tight fit to the shaft. It is hard to press the wheels into the shafts, but if you used the provided screws, you can fit them very easily by screwing them in.

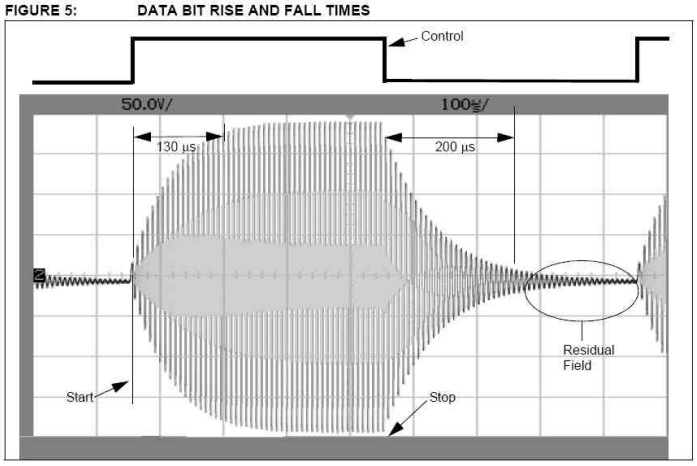
Sending Commands From the Remote to the Robot

- 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 five commands required:
  - **Move Left.**
  - **Move Right.**
  - **Move Forward.**
  - **Move Backward.**
  - **Stop.**
- Use buttons, PuTTY, nunchuck, joystick, etc. to select commands.

Data Bit Rise and Fall Times

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

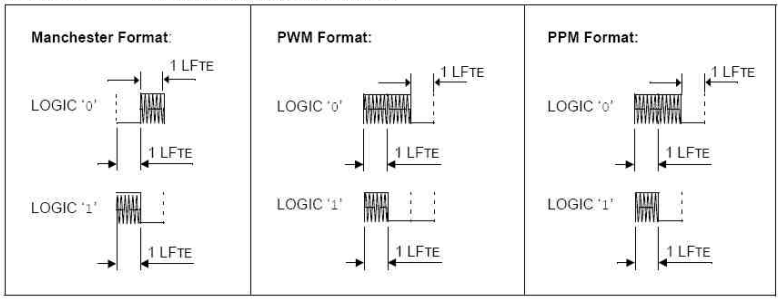
FIGURE 5: DATA BIT RISE AND FALL TIMES



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.

Use EFM8 second UART!

- The EFM8LB1 comes with two UARTs:
  - UART0: is the standard serial port that comes with most 8051 compatible microcontrollers.
  - UART1: is an enhanced UART available in many Silabs microcontrollers. Example posted in Connect.
- To modulate the magnetic field, you can use UART1 at a very low baud rate. 110 baud worked for me. The faster the better!

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 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.
- Brand name batteries have lower internal resistance, but they are more expensive.

WARNING!

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

Extra requirement: Add this sign to your transmitter. →

Project 2 Due Dates

Function demo: March 28/29

Report: April 6