Electronics Technology and Robotics III
Control and Navigation 4

(Notes primarily from "Underwater Robotics – Science Design and Fabrication", an excellent book for the design, fabrication, and operation of Remotely Operated Vehicles ROVs)

- **Administration:**
  - Prayer
- **Analog-to-Digital Conversion:**
  - As stated in Lesson 20, Control and Navigation 3, the physical world is naturally analog and the sensors that measure the world may output analog signals. However, computers, microcontrollers, and many other electronic devices utilize digital signals solely. There is a way to convert analog signals to digital signals (A/D converter or ADC – Analog-to-Digital Conversion).
    - Because noise interferes with analog signals more readily than digital signals, it is best to convert an analog signal to a digital signal close to the analog sensor.
  - Specialized integrated circuit chips perform ADC and microcontrollers can contain ADC modules that can perform ADC internally. Registers in the MCU's software must be configured to control the operation of the analog/digital pins, i.e., whether the pin operates as an analog input or a digital input/output.
  - The sensor output range should match the input range of the A/D converter, for example, 0 to +5 volts or -10 to +10 volts. Small signals may need amplification to make them large enough to match the input range of the A/D converter.
  - The A/D converter assigns a distinct output digital value to the input analog signal. For example, an 8-bit A/D converter (256 values, $2^8 = 256$) with an input range of 0 to +5 volt has a resolution of 0.01953 V (5.0 V/256 = .01953125 V or 19.53 mV). If the analog input voltage is 3.09 volts, the A/D converter would assign a value of 158 to the reading since A/D converters assign only integer values (3.09/0.01953 V = 158.22). See Figure 1.

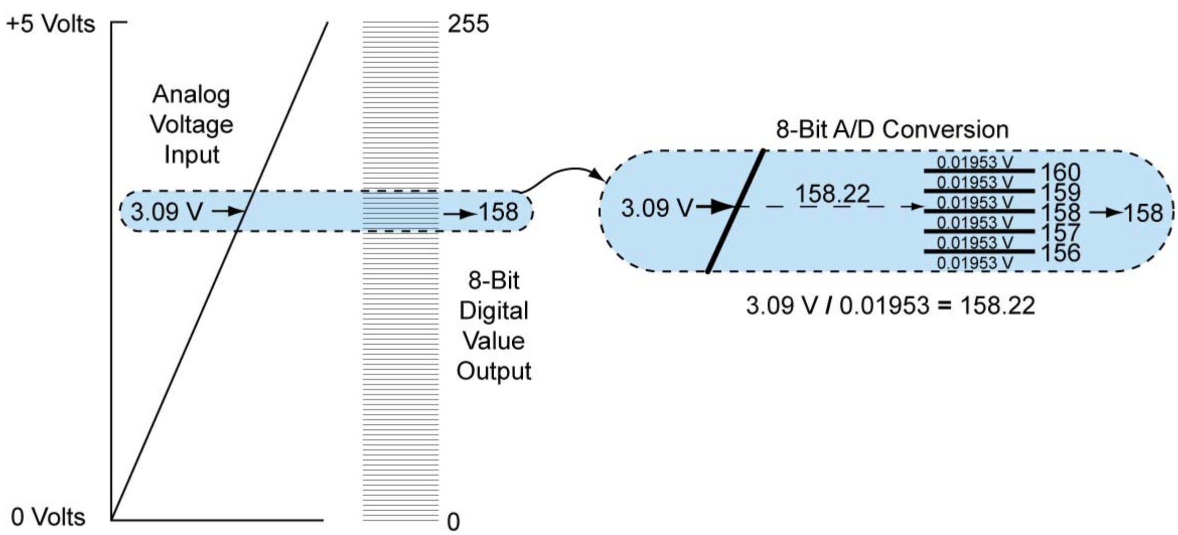


Figure 1: An Example of 8-Bit Analog-to-Digital Conversion

If a higher resolution is needed, a 10-bit A/D converter would furnish a 0.00488 volt resolution (1024 digital values); a 12-bit converter gives a 0.00122 volt resolution (4096 digital values).

- **Signal Multiplexing:**
  - It is impractical for a sophisticated ROV with a long tether to have a separate wire pair for each electrical device onboard; the tether would be thick and unmanageable.
  - Signal multiplexing makes it possible to replace all of the separate wire with a single pair power cable and one small control wire.

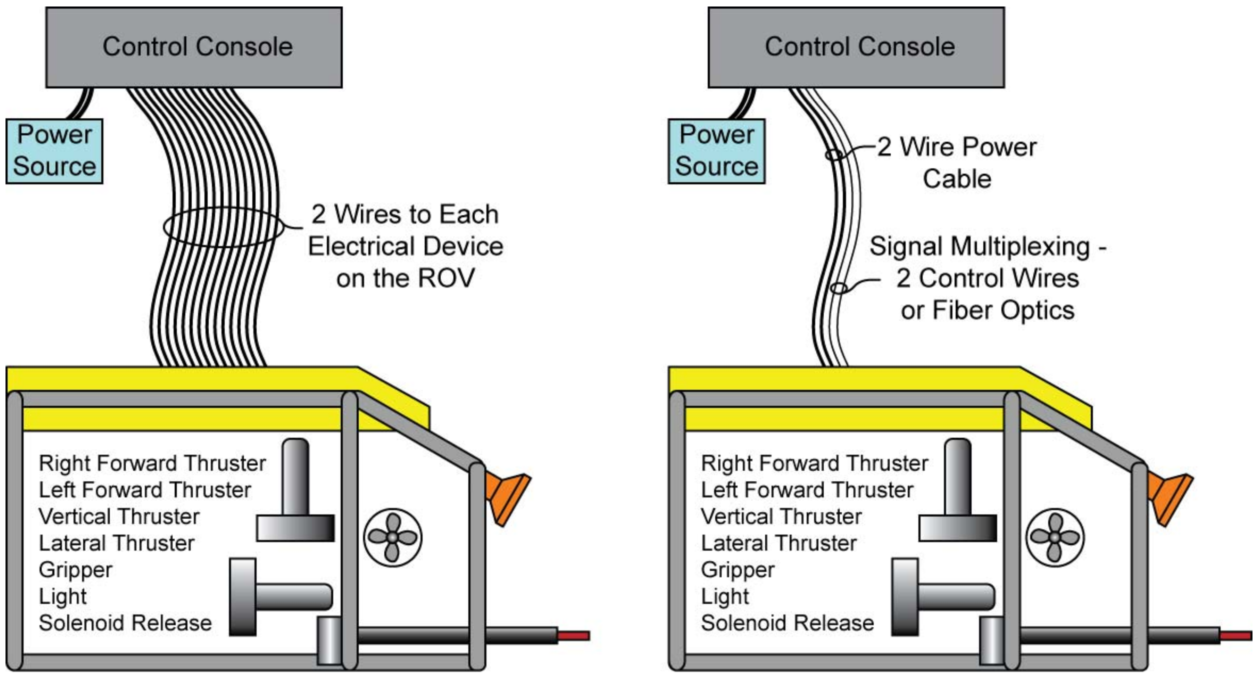


Figure 2: Signal Multiplexing Can Significantly Reduce the Size of the Tether

  - Several Methods of Signal Multiplexing:
    - Frequency Division Multiplexing: Data is be transmitted separately on different frequency channels.

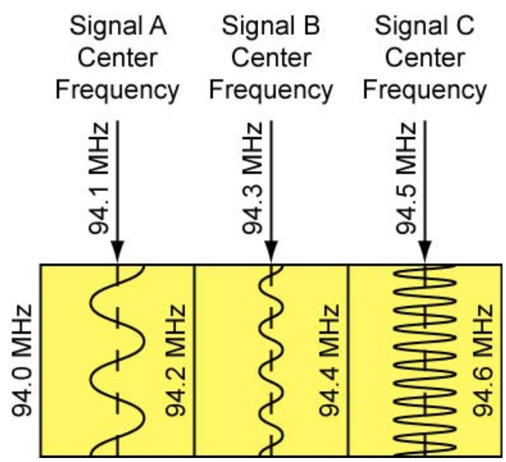


Figure 3: Frequency Division Multiplexing - Each Signal Has a 200 kHz Bandwidth

- Time-Division Multiplexing: Signals take turns being sent over the same wire or channel. Low-bit-rate data streams can be merged into one high-bit-rate multiplexed data stream. See Figure 4.

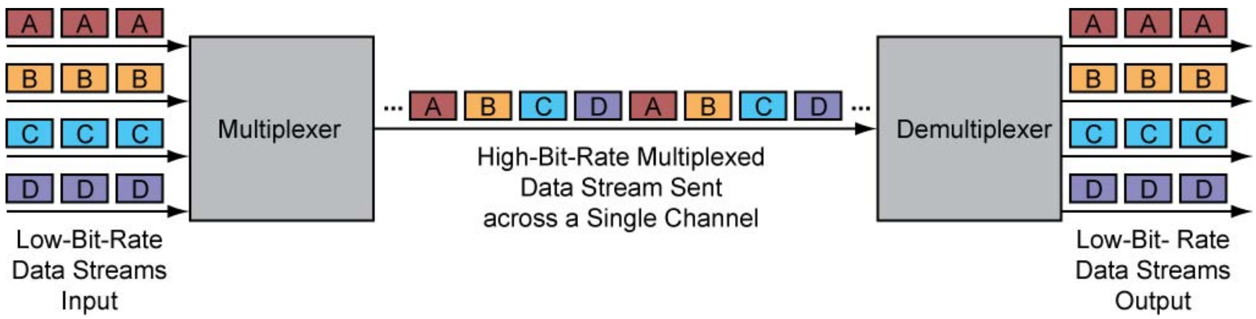


Figure 4: Time-Division Multiplexing

- Commercial multiplexers (MUX) are available for data transmission. On the transmitting end, a multiplexer (mux) combines many signals onto one channel; on the receiving end, a demultiplexer (demux) splits the multiplexed signal back into the various original signals.
- For details and labs on multiplexing, refer to the lesson on Multiplexing at: http://cornerstonerobotics.org/curriculum/lessons_year3/eriii23_control_navigation6.pdf

- **Electronic Sensors and Sensor Circuits:**
  - Now we will cover in more practical detail, how to use a microcontroller to electronically communicate with our ROV. We will learn how to:
    - Connect inputs to a microcontroller to receive information from the ROV pilot or sensors.
    - Wire outputs to the microcontroller to control actuators such as thrusters and onboard tools.
    - Use PicBasic Pro software to manage the input and output functions of the microcontroller.
  - Connecting a Pushbutton to Your Microcontroller:
    - The most basic input to a microcontroller is a single bit of information (1 or 0, high or low, ON/OFF). For example, a pilot may send an ON/OFF signal to a MCU to turn ON a thruster or an ROV light.
    - Different pushbutton switches can be connected to different Input/Output (I/O) pins on the microcontroller so the MCU can know which pushbutton is pushed.

- Normally Open Pushbutton Momentary Switches:

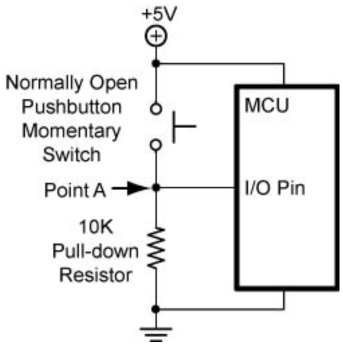


Figure 5: The I/O pin remains low until the pushbutton is pressed, then the I/O pin becomes high (active high).

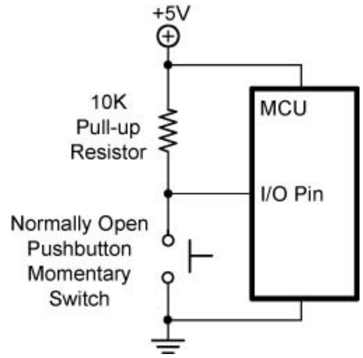


Figure 6: The I/O pin stays high until the pushbutton is pushed, at which point, the I/O pin is driven low (active low).

Let us focus on Figure 5. When the pushbutton switch is open, there is practically no current flowing through the 10K pull-down resistor. Therefore, the voltage at point A is the same as ground (0 volts), since there is no voltage drop across the 10K resistor. The MCU pin is held to low (0 volts) until the switch is closed, at which point the MCU pin is driven high (+5 volts) by the direct connection to +5 V. The pull-down resistor is used to hold the I/O pin to a zero volts (low). The resistor "pulls" the voltage "down" to 0 V. If nothing is connected to the I/O pin, the voltage at that pin is considered to be “floating”, i.e., some unknown voltage between 0 and +5 volts. The 10K resistor allows the pin to keep at a steady state of 0 volts until the pushbutton switch is pressed. When the switch is pressed, only 0.0005 amps flows through the 10K pull-down resistor.

$$V = I * R$$
$$I = V / R$$
$$I = 5V / 10{,}000 \text{ Ohms}$$
$$I = 0.0005 \text{ A}$$

- Normally Closed Pushbutton Momentary Switches:

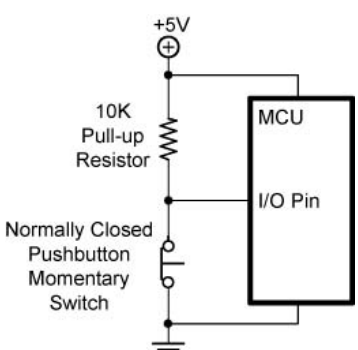


Figure 7: The I/O pin is low until the normally closed switch is pushed; then the I/O pin is forced high (active high).

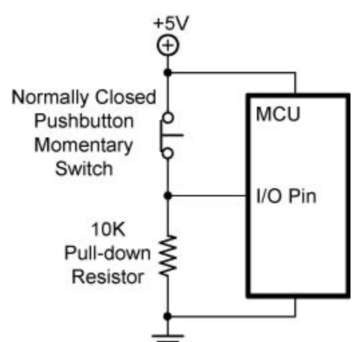


Figure 8: The I/O pin remains high when the pushbutton is not pressed, but when depressed, it is compelled to go low (active low).

The pull-up and pull-down resistor’s value vary from 1K to 47K.

- o Using a Potentiometer for Adjustable Input:
  - Potentiometers: A potentiometer is a type of variable resistor that is used in circuits having low power. They are used to divide voltage and they come with three terminals.
  - Symbol:

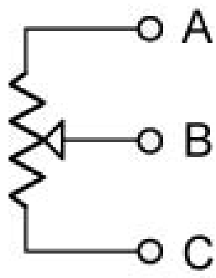


Figure 9: Potentiometer Symbol

The resistance between A and C is constant and also the value of the potentiometer. The resistance between A and B & B and C changes according to the position of the wiper.

  - Construction: Potentiometers can be rotary and linear.

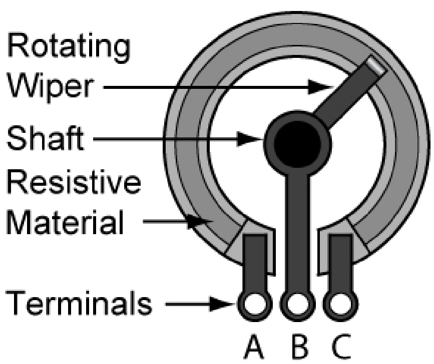


Figure 10: Basic Rotary Potentiometer Construction

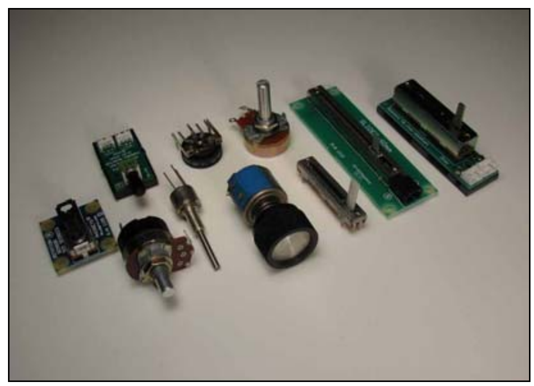


Figure 11: An Assortment of Rotary and Linear Potentiometers

  - Moving the wiper of a potentiometer: In the figures below, the resistance R_{AC} remains 100 Ohms in all three cases. R_{AB} and R_{BC} change as the wiper rotates.

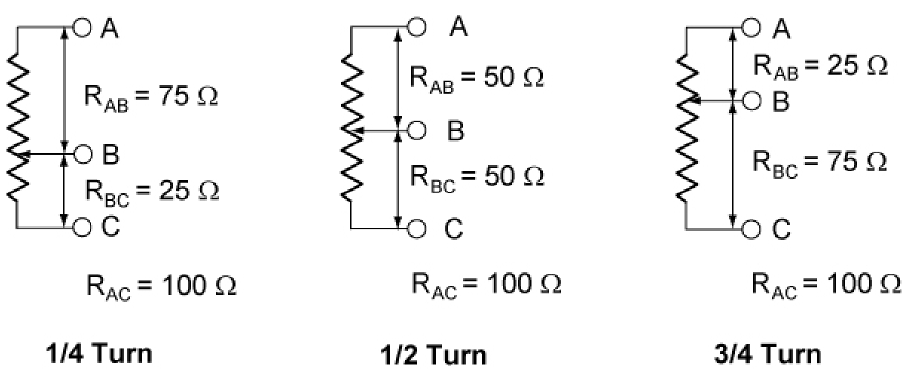


Figure 12: 100 Ohm Potentiometer Resistances at Several Positions

If 10.0 volts is applied across the two end terminals A and C, the voltage on terminal B varies from 0 to 10.0 volts. The potentiometer acts as a voltage divider.

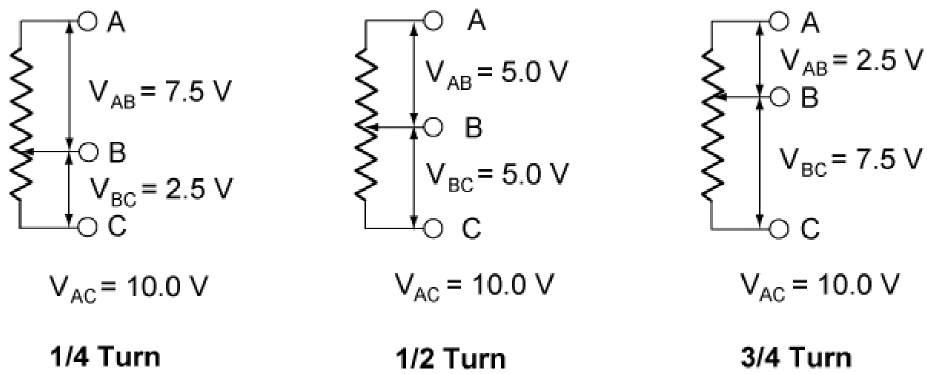


Figure 13: Using a Potentiometer as a Voltage Divider

- The value printed on a potentiometer is its maximum value (R_{AC}).
- The output of a potentiometer can be fed into the A/D converter module of a microcontroller to then be used to control the desired device. See Figure 13. The potentiometer can control brightness of a light, the rotational speed of a motor, the position of a servo motor, the volume of a speaker, etc.

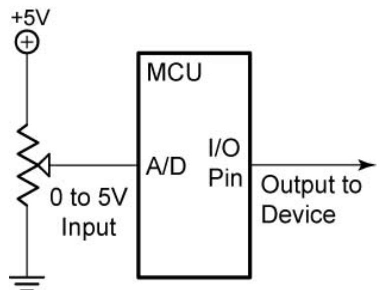


Figure 14: A Potentiometer Connected to the A/D Module in an MCU to Control a Device

- Perform Control and Navigation 4 Lab 1 – Reading a Potentiometer
- A ROV would use two microcontrollers, one at the surface and the other embedded on the ROV.

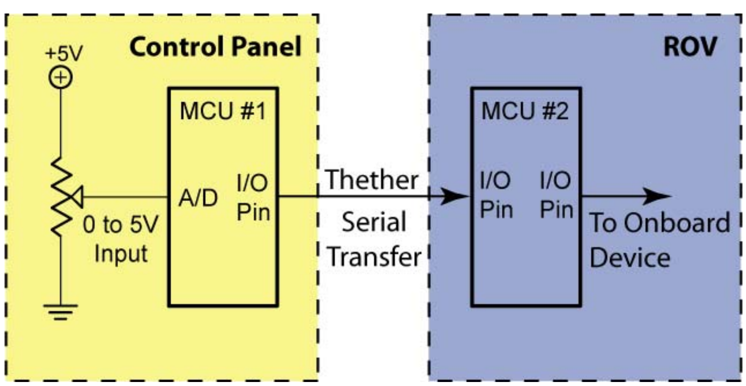


Figure 15: Link between MCU in the Control Panel and the MCU on the ROV

- Joystick Control:
  - The X and Y controls inside a joystick usually have two potentiometers at right angles to each other (Figures 16 and 17).

Figure 16: Mini-Joystick with Two Small Potentiometers at Right Angles

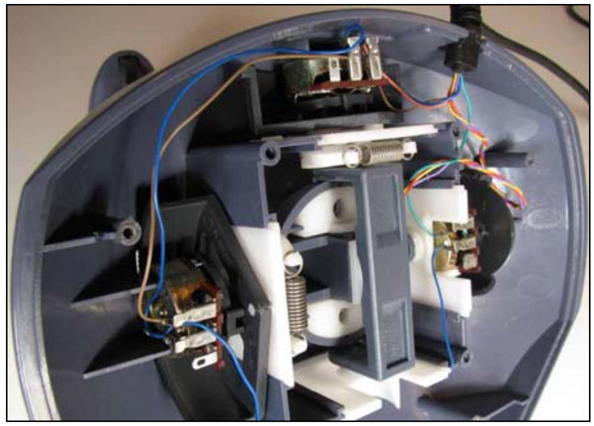
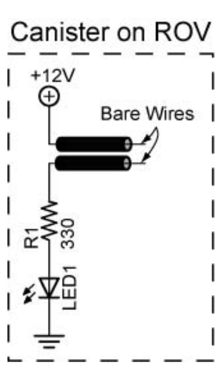


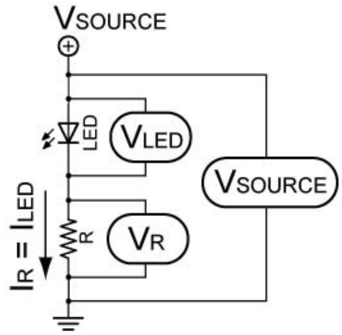
Figure 17: Joystick with Three Potentiometers, Two for the Joystick and One for the Thumb Turn

  - Older joysticks such as the one in Figure 17 send the analog voltages to the A/D converter in the computer. Newer joysticks contain internal A/D converters and send digital signals out. You can modify or hack joysticks by bypassing the internal A/D converter and wiring directly from the potentiometers into your microcontroller A/D converter.
  - See the textbook for instructions regarding radio controlled (R/C) joysticks.
- Leak Detection Sensor:
  - This is the first sensor that we will discuss that is mounted on the ROV. It is a relatively simple sensor yet it gives the ROV pilot an alarm signal so that they can return the vehicle to the surface and try to save onboard systems.
  - Indicator on the ROV: A simple LED circuit is placed inside a canister on the ROV so that the LED is in view of a camera. The bare wires are positioned at the bottom of the canister. If water intrudes into the canister, it will contact both bare wires, completing the circuit and the LED lights.



Note: The value of the current limiting resistor R1 is dependent upon the forward voltage and maximum current of LED1. Refer to Figure 19 below for R1 calculation.

Figure 18: LED Leak Detector Contained Onboard the ROV



LED Resistor Worksheet		
V_{LED} =	2.0 V	From LED Data Sheet
I_{LED} =	30 mA = 0.030 A	From LED Data Sheet
V_{SOURCE} =	12 V	
$V_R = V_{SOURCE} - V_{LED}$	V_R = 12 V - 2 V = 10 V	
$I_R = I_{LED}$	30 mA = 0.030 A	
$R = V_R/I_R$	R = 10V/0.030A = 333 Ω	

Since 333 ohms is not a standard resistor value, use 330 ohms as this application is not critical of values

Figure 19: Calculating the Current Limiting Resistor in an LED Circuit

- Indicator at the Surface: The LED circuit can be located on the pilot's control console rather than on the ROV. A transistor amplifies the signal from the ROV, lighting the LED if water is present.

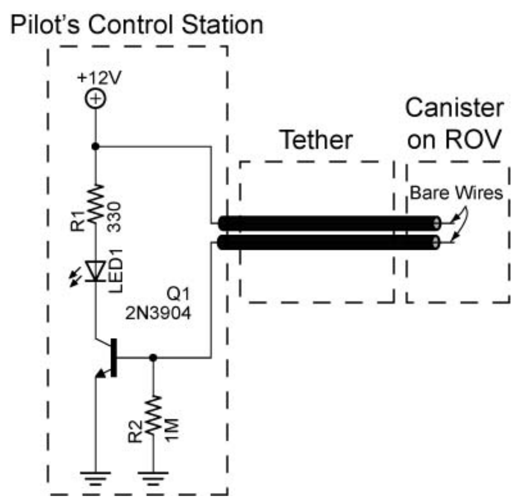


Figure 20: LED Leak Detector Mounted on Pilot's Control Panel

- Voltage Sensor:
  - It is helpful to know how much energy is left in your batteries, especially in your batteries are onboard the vehicle.
  - Another application for the voltage sensor is to measure the working voltage on the ROV with the battery at the surface. This gives the voltage drop in the tether power feed under varying loads.
  - You can build our own voltage sensor circuit using a voltage divider to scale down the battery voltage to match the microcontroller A/D input. The MCU can then send the data to the surface for display.
  - Perform Control and Navigation 4 Lab 2 – Voltage Sensor

- Compass:
  - A compass onboard is one of the basic navigational tools which can aid with navigation in waters with low visibility and also keep track of how many times the ROV has rotated.
  - The easiest way to equip an ROV with a compass is to set a waterproof compass in view of a camera.
  - Test the placement of the compass on the ROV as metals, motors, and onboard electronics can interfere with your compass readings.
  - Digital compasses are available with varying resolutions. In Control and Navigation 1, Lab 1, the digital compass had four signal lines – one for each compass direction. See: http://cornerstonerobotics.org/curriculum/lessons_year3/eriii18_control_navigation1.pdf In Control and Navigation 4 Lab 3, the Parallax HMC5883L Compass Module has a 1 to 2 degree compass heading accuracy.
  - Perform Control and Navigation 4 Lab 3 – Parallax HMC5883L Compass Module.
- Depth Sensor:
  - Again, the simplest way to monitor the depth of a dive is to place a diver's depth gauge in view of a video camera.
  - Electronic Depth Sensors:
    - Normally, an electronic pressure sensor is made of a diaphragm construction that has strain gauges bonded to it, acting as resistive elements. Under the pressure-induced strain, the resistive values change. The strain gauges are connected into a Wheatstone bridge circuit with a combination of four active gauges (full bridge). This results in a signal output, related to the stress value. As the signal value is small, (typically a few millivolts) the signal conditioning electronics provides amplification to increase the signal level to 5 to 10 volts.

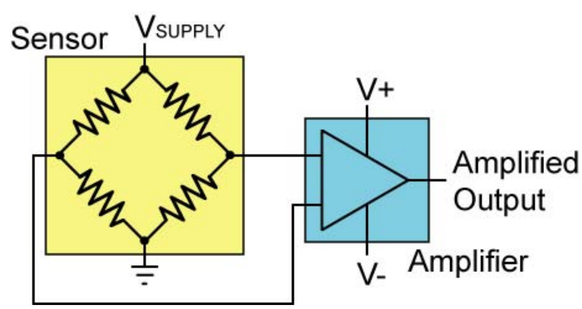


Figure 21: Wheatstone Bridge Circuit

  - For additional information regarding the operation of electronic pressure sensors, see: http://www.sensorland.com/HowPage004.html
  - For additional information regarding Wheatstone bridges including a building a pressure sensor activity, see: http://scme-nm.org/index.php?option=com_docman&task=cat_view&gid=88&Itemid=53

- Reference Pressures: There are several different pressures available on the side of the membrane opposite the measured pressure.
  - Absolute: The reference pressure is a vacuum and these gauges read 1 atm at sea level.
  - Gauge (Textbook): The reference pressure is 1 atm and these gauges read 0 atm at sea level.
  - Gauge (Standard): Sensor measures the pressure relative to the ambient atmospheric pressure. (A form of a differential pressure gauge)
  - Relative or Differential: The reference pressure is supplied through a second port on the side of the membrane opposite the measured pressure.

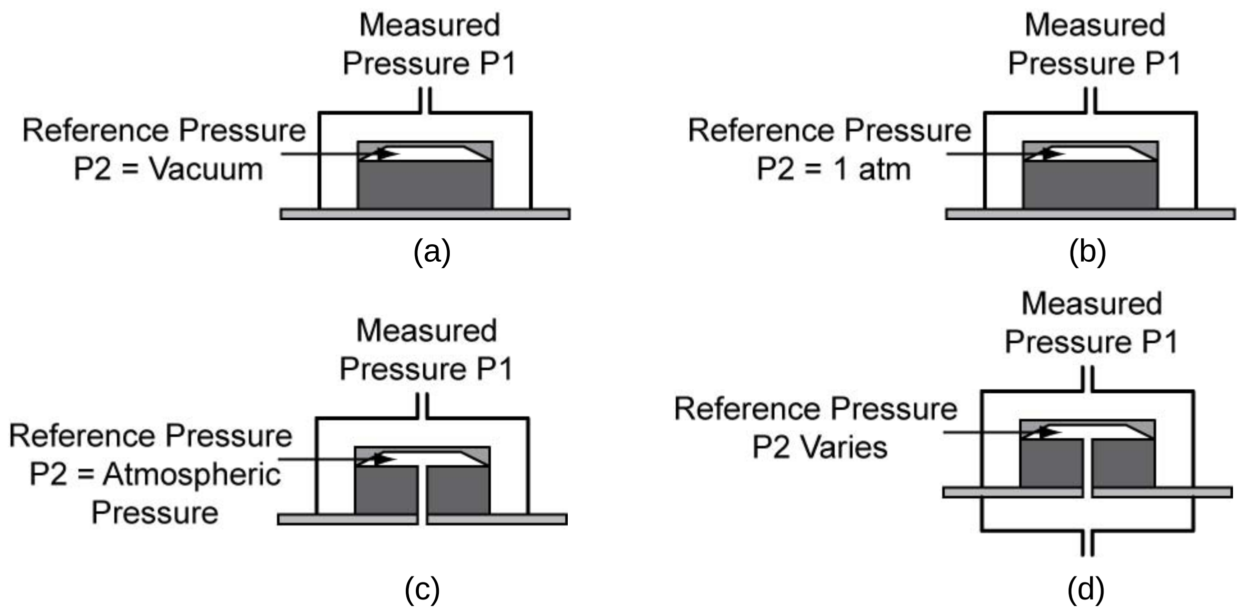


Figure 22: Absolute (a), Gauge (Textbook) (b), Gauge (Standard) (c), and Relative Pressure (d) Sensors

- Perform Control and Navigation 4 Lab 4 – MPX4520AP Integrated Pressure Sensor as a Water Depth Sensor.

o Global Positioning System:
- As stated in lesson Control and Navigation 1, the Global Positioning System (GPS) is a radio navigation system that allows land, sea, and airborne users to determine their exact location, velocity, and time 24 hours a day, in all weather conditions, anywhere in the world.
- GPS is available as a completed consumer package or an OEM (original equipment manufacturer). See Figure 23.

Figure 23: GPS in a Consumer Package and an OEM GPS

        - Integrating an OEM GPS into an AUV requires the programming skill to sort through the GPS data output and then apply that data in useful navigation calculations.
    - Sonar:
        - An OEM echosounder altimeters are available for installation on your ROV, but they also require programming skill to use the data output.
        - The web offers resources on how to hack off-the-shelf sonar fish finders to equip your ROV with sonar.
    - Other Sensors:
        - Three axis accelerometers can monitor your ROV's pitch and roll and help with navigation and dynamic stability.
        - Touch sensors can indicate when your vehicle has made contact with another object or the force exerted by a gripper.
        - Temperature, chemical, conductivity, turbidity, and other sensors are offered to monitor the water quality of the ROV's environment.
- **Data Display Options:** Here are four ways for the ROV pilot to view the sensor data.
    - Place the sensor equipped with a visible display in view of onboard video camera.
    - On-Screen Display (OSD) or Text-on-Video: This technique displays the data directly on the pilot's monitor. See the BOB-4 from Decade Engineering: http://www.decadenet.com/
    - Equip your console with an LCD linked to your ROV sensors through a microcontroller.
    - If the ROV has an onboard Ethernet controller with the ability to serve web pages, you could use a web page to display sensor data.

Electronics Technology and Robotics III
Control and Navigation 4 LAB 1 – Reading a Potentiometer

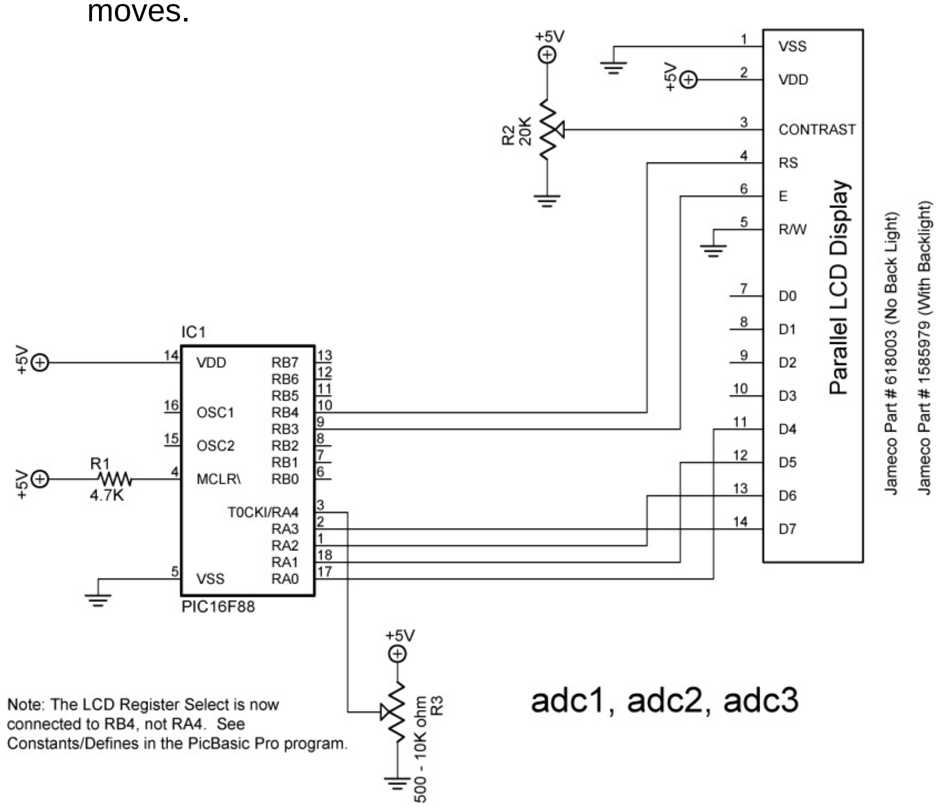
- **Purpose:** The purpose of this lab is to acquaint the student with wiring a PIC16F88 for analog/digital conversion and to expose the student to the PicBasic Pro command ADCIN and to a linear slide sensor.

- **Apparatus and Materials:**
    - 1 – Breadboard with +5V supply or an Analog/Digital Trainer
    - 1 – PIC 16F88 Microcontroller
    - 1 – 10 K Tripot
    - 1 – Phidgets Slide Sensor, Product # RB-Phi-20 from:

http://www.robotshop.ca/home/products/robot-parts/sensors/linear-rotary-resistors/index.html

    - 2 – 150 Ohm, ½ Watt Resistors
    - 1 – 10 K Ohm, ½ Watt Resistor
    - 1 – 1K, ½ Watt Resistor
    - 1 – NO Momentary Switch
    - 2 – LEDs

- **Procedure:**
    - Wire the circuit below. Use a 10K tripot for R3. Make sure to read the note in the schematic.
    - Program the PIC16F88 with **adc1.pbp**, **adc2.pbp**, and then **adc3.pbp**. Adjust R3 and note the values on the LCD screen for each program.
    - Now substitute the slide sensor for the 10K tripot. Note the changes in the LCD value as the linear position of the slide sensor moves.

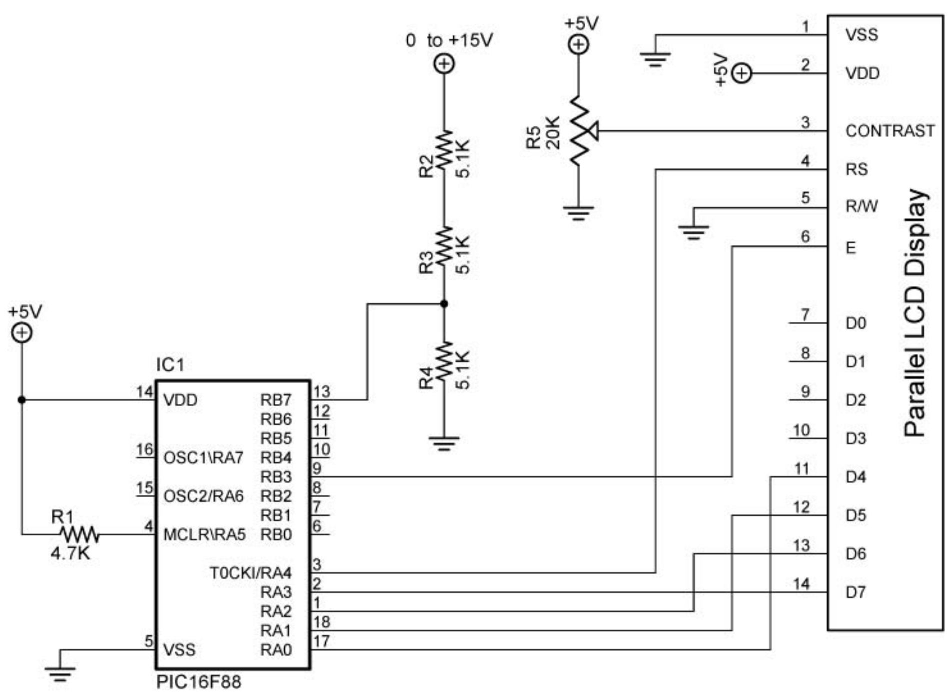


Electronics Technology and Robotics III
Control and Navigation 4 LAB 2 – Voltage Sensor

- **Purpose:** The student wires a circuit and programs a PIC16F88 to measure and display voltages from 0 to +15 volts.

- **Apparatus and Materials:**
  - 1 – Breadboard with +5V Supply (Separate from 15 Volt Power Supply)
  - 1 – 15 Volt Power Supply
  - 1 – PIC16F88 Microcontroller
  - 1 – 16x2 Parallel LCD Display, Jameco Part # 618003
  - 1 – 20K Tripot
  - 1 – 4.7K Ohm, ½ Watt Resistors
  - 3 – 5.1K Ohm, ½ Watt Resistors

- **Procedure:**
  - Wire the circuit below and program the PIC16F88 with read_voltage.pbp. See: http://cornerstonerobotics.org/code/read_voltage.pbp
  - Connect the 15 volt power supply across the 3 – 5.1K resistor voltage divider and adjust the input voltage from 0 to +15 volts.



Read_Voltage Circuit

  - A word of caution about accuracy:
    - The accuracy of the resistors used in the divider has a direct impact upon the accuracy of the voltage reading. Use resistors with low tolerance to increase the accuracy.

- The LCD voltage reading uses the PIC16F88 power supply as the reference voltage which may not be very accurate (e.g., a 7805 5V regulator has an accuracy of 4%, the output voltage = 4.8 – 5.2V). The most accurate way of all will be to use a voltage reference and feed this into RA3 as the positive reference value. See the ADCON1 register in the PIC16F88 datasheet to set the A/D voltage reference configuration bits.
- Thanks to T. Angerhofer for his assistance in this lab.

Electronics Technology and Robotics III
Control and Navigation 4 Lab 3 – Parallax HMC5883L Compass Module

- **Purpose:** The student becomes familiar with the hardware and software to operate the Parallax HMC5883L Compass Module.

- **Apparatus and Materials:**
  - 1 – Parallax HMC5883L Compass Module
    - Datasheet: http://www.parallax.com/Portals/0/Downloads/docs/prod/sens/29133-CompassModuleHMC5883L-v1.0.pdf
    - Sources:
      - http://www.parallax.com/StoreSearchResults/tabid/768/List/0/SortField/4/ProductID/779/Default.aspx?txtSearch=hmc5883l+compass+
      - http://www.robotshop.com/parallax-3-axis-hmc5883l-compass-module.html
  - 1 – Parallax P8X32A Quick Start Board
    - Features, Setup, and Programming, and Specifications: http://www.parallaxsemiconductor.com/quickstart
    - Sources:
      - http://www.parallax.com/StoreSearchResults/tabid/768/txtSearch/P8X32A/List/0/SortField/4/ProductID/748/Default.aspx
      - http://www.robotshop.com/parallax-propeller-p8x32a-microcontroller-quickstart.html?utm_source=google&utm_medium=base&utm_campaign=jos
  - 1 – USB A to mini B Cable
    - Source: http://www.parallax.com/Store/Accessories/CablesConverters/tabid/166/txtSearch/P8X32A/List/0/SortField/4/ProductID/33/Default.aspx

  - 1 – Small or Mini Breadboard
  - Homemade or Commercial Jumper Wires.
    - Source: http://www.jameco.com/webapp/wcs/stores/servlet/Product_10001_10001_126342_-1
- **Procedure:**
  - Connections:
    - Plug in the Parallax P8X32A Quick Start Board into the computer using the USB A to mini B cable. The green power indicator LED on Propeller should light up. The red and blue transmit and receive LEDs may flicker.

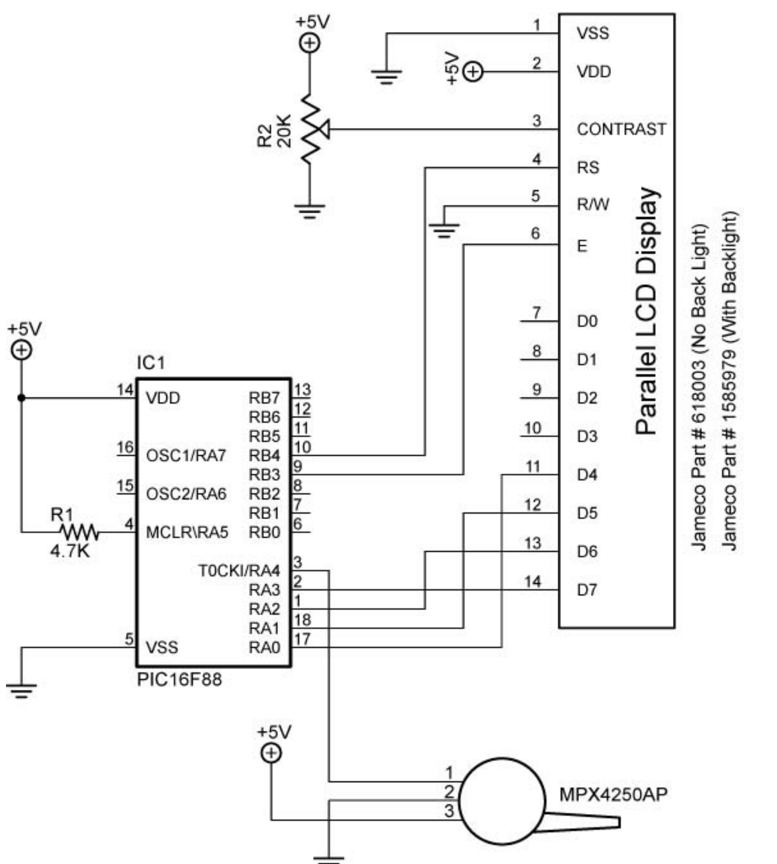
- Compass Module to QuickStart board connections:

Compass Module	Propeller QuickStart Header
GND	Pin 39 (GND)
VIN	Pin 38 (3.3V)
SCL	Pin 1
SDA	Pin 2

- For Parallax Propeller Fundamentals, see: http://www.parallax.com/Portals/0/Downloads/docs/prod/prop/PELabsFunBook-v1.1.pdf
- Download the Propeller/Spin Tool Software v1.2.7 (R2) software.
  1. To download, go to http://www.parallax.com/tabid/442/Default.aspx.
  2. Click on the folder to the right of [**Propeller/Spin Tool Software v1.3.2 (R2)**].
  3. Opening Setup-Propeller-Tool-v1.3.2 (R2) window appears.
  4. Press the Save File button.
  5. On the Menu Bar, Click Tools and select Downloads.
  6. From the Downloads Menu, choose Setup-Propeller-Tool-**v1.3.2 (R2).exe**.
  7. Run the installation program.
  8. If you have issues Google specific error codes or consult: http://www.parallax.com/ProductInfo/Microcontrollers/PropellerGeneralInformation/PropellerDownloads/PropellerToolSoftware/tabid/609/Default.aspx.
  9. Now go to the HMC5883L Compass Module web page at: http://www.parallax.com/Store/Sensors/CompassGPS/tabid/173/ProductID/779/List/0/Default.aspx?SortField=ProductName,ProductName
  10. Download the Compass Example Spin Source Code.
  11. When the CompassSpinDemo.zip folder appears on the screen, extract the three .spin files to the Desktop.
  12. In the Program list, open the Parallax folder and then open the Propeller Tool v1.3.2 (R2) folder.
  13. Load the Propeller Tool v1.3.2 (R2) program.
  14. Open the HMC5883L_demo.spin file from the Desktop into the Propeller Tool v1.3.2 (R2) program.
  15. Click on the HMC5883L_demo tab and then at the top of the page, click Run>Compile Current>Load EEPROM. The blue & red LEDs on Propeller will blink.
  16. Now click HMC5883L_demo tab and then at the top of the page, click Run>Indentify Hardware to determine which COM port Propeller is connected to.
  17. Again return to the Program list and open the Parallax folder and then reopen the Propeller Tool v1.3.2 (R2) **[folder]**.
  18. This time load the Parallax Serial Terminal program.
  19. Set the Com Port to the port identified above.
  20. Set the Baum Rate to 9600.
  21. Click on the Enable button.
  22. The Raw X,Y,Z and Heading in Degrees should be displayed.

Electronics Technology and Robotics III
Control and Navigation 4 Lab 4 – MPX4520AP Integrated Pressure Sensor as a Water Depth Sensor

- **Purpose:** The student becomes familiar with the hardware and software to operate the MPX4520AP integrated pressure sensor. Note, the MPX4250AP is specifically designed to sense the absolute air pressure within the intake manifold. Our application under water stretches its intended purpose.
- **Apparatus and Materials:**
  - 1 – Breadboard with +5V Supply
  - 1 – MPX4520AP Absolute Integrated Pressure Sensor
    - 2.9 – 36.3 psi, 0.2 – 4.9 V Output
    - Source: http://www.digikey.com/product-detail/en/MPX4250AP/MPX4250AP-ND/464053
    - Datasheet: http://www.freescale.com/files/sensors/doc/data_sheet/MPX4250A.pdf
  - 1 – 20K Tripot
  - 1 – 4.7K Resistor
  - 1 – PIC16F88 microcontroller
  - 1 – LCD Display (Jameco #618003 or #1585979)
- **Procedure:**
  - Wire the circuit below and program the PIC16F88 with mpx4250.pbp (look under “PicBasic Programs>Reading Sensor Programs” at http://cornerstonerobotics.org/).



MPX4250AP Pressure Sensor

- You may have to modify the water depth equation. Our MPX4250AP read 92 just above the water and 107 at a depth of 5’ of water (hence the coordinates (92,0) and (107,5).