Beavertronics 5970

Electrical Enchiridion

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Introduction: The Basics

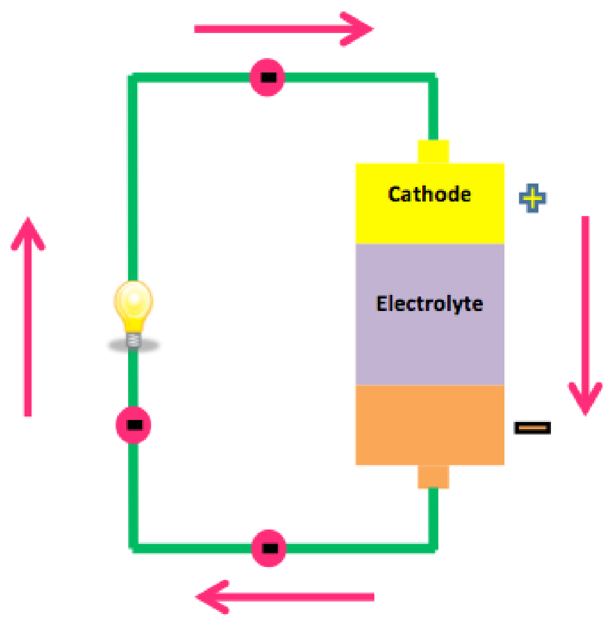
So, you're interested in electrical? Aren't sure where to start? You've come to the right place! This interactive Beavetronics 5970 Electrical Enchiridion will kickstart you into a field of engineering you simply won't be able to *resist*. Please, enjoy! Let us know if there's any way we can improve by contacting beavertronics5970@gmail.com.

What is electricity?

To understand the basic electrical theory, one must understand the following terms:

- Electron
- Current
- Ampere
- Voltage
- Resistance

Electricity in its simplest definition is the flow of electrons from a negative to a positive charge, as modeled in the photograph below.

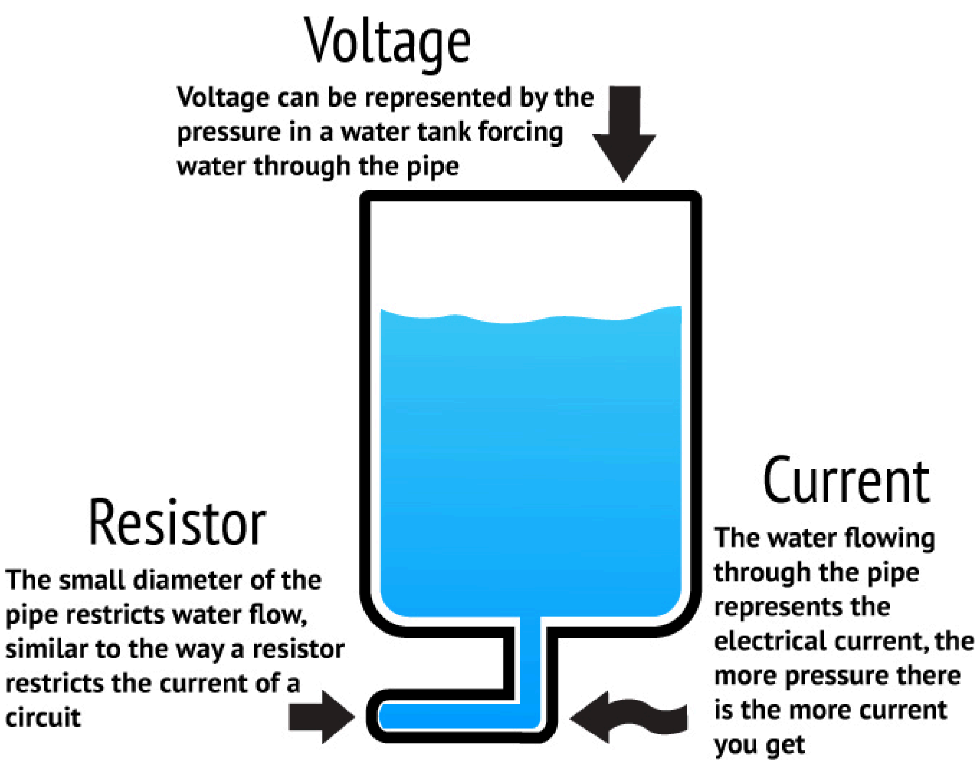


Electric flow is described as a current, of which there are two types: direct current (DC) and alternating current (AC). Direct current is unidirectional and exhibits a constant voltage polarity; that is, electrons only flow in from point A to B around a circuit, never significantly wavering in the potential energy driving the electrons forward. For our purposes, DC is most important to understand since FRC uses DC batteries and motors. If you're interested in learning a bit more about how AC works, watch this video.

Click here for a DC current simulation!

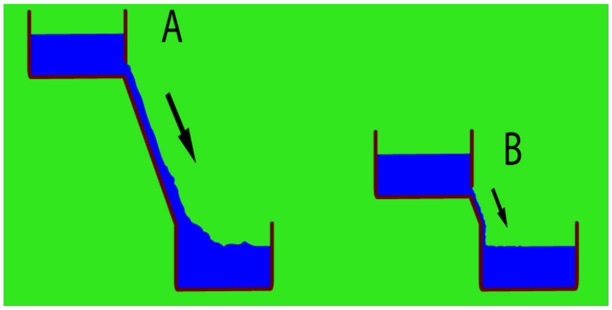
Amperes are the unit measure of current, that is, the rate of displacement of electric charge. One ampere is equivalent to one coulomb per second flowing through a circuit. (see below for further definition of a coulomb)

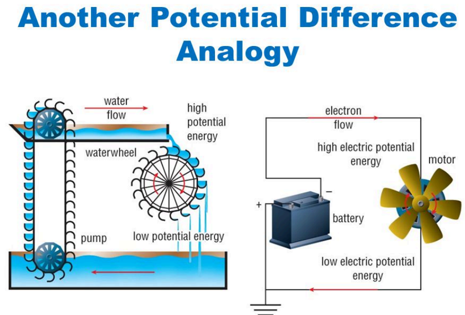
Whether you have previously studied the electrical theory or not, you have most likely heard the term ‘voltage’ thrown around before. Voltage “pushes” electrons around a circuit; a common analogy for circuits is a water pipe system, where voltage would describe the water pressure pushing water through the end of a pipe due to a limited volume and driving force. The higher the voltage, the higher (stronger, faster) the current (assuming nothing else has changed), however, voltage can be measured independently of current.



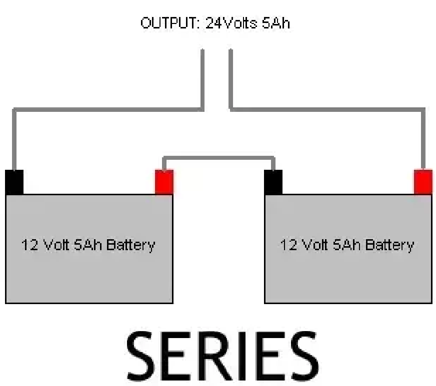
To learn about how voltage is measured, visit How to Use a Multimeter.

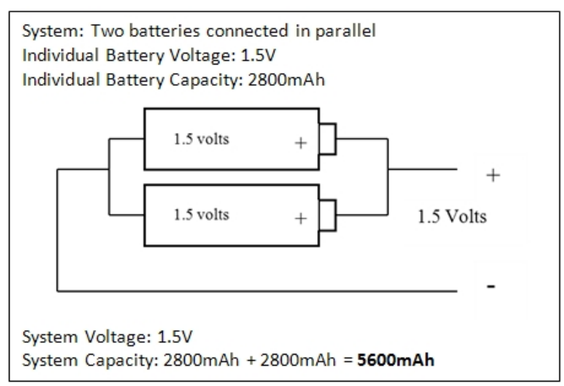
Voltage can also be described as the potential difference, which demonstrates how much work can potentially be done by a circuit. As practice, ask yourself which - A or B - would have a higher voltage in an electrical system?





From the left picture above, you should have concluded that A exhibits a higher voltage if the analogy was translated to an electrical circuit. This would imply that there are more excited electrons in the anode rather than cathode end of a battery. Therefore, when the energized electrons of the anode experience a high potential energy are pushing their way towards the cathode, we can harness this potential difference to do work in the circuit. Potential difference can be “boosted” by adding batteries in series, since all electrons are flowing in the same direction but are encountering more available energy along their path, thus, current flows faster. If this circuit was constructed to light an LED, the light would become more intense with this increase in voltage. Whereas, when batteries are in parallel, electrons are not boosted but rather there are a greater number at the same voltage, thus a powered LED will be illuminated for longer but at a lower intensity than in series.





Voltage is distinctive of volts as volts are the unit of measure for voltage, the pressure or potential difference itself. One volt will drive one coulomb through a resistor of one ohm per second. One coulomb is equivalent to approximately 6,242,000,000,000,000,000 electrons per second. To power an 1.5 Watt LED with a 1.5V battery, 6,242,000,000,000,000,000 electrons would be needed to flow through the negative to positive ends of the LED every second. If too many electrons try to pass through the LED at once, then it will burn out; thus, resistance is needed.

To understand resistance one must first understand Ohm's Law:

$$V = IR$$

Ohm's law says that the voltage (volts; V) is equivalent to the current (amps; A) multiplied by resistance (Ohms; Ω). Resistance describes the repulsion against current flow; when an electron acts against its neighbors, friction occurs and heat is produced. A classic example of resistance causing heat is a lightbulb, where a filament inside is heated to the point of illumination.

Why would resistance matter? Resistance occurs naturally in all wires, but in order to ensure the proper and consistent function of a circuit, resistance must sometimes be added to regulate amperage (which, in turn, affects voltage due to an altered level of potential energy). For example, if we have a 9V battery rated at 0.02A and wish to use it to power an LED with a recommended current at 0.018A, then without adding resistance to the circuit, calculations will look like this:

$$V = IR$$

$$9V = I*0\Omega$$

$$\therefore I = \frac{9V}{0\Omega}$$

In other words, since we are dividing by zero, the LED will be bombarded with unlimited current, since resistance is approximately zero Ohms. To decide which resistor to include in your circuit, calculations can determine the desired Ohm value:

$$V = IR$$

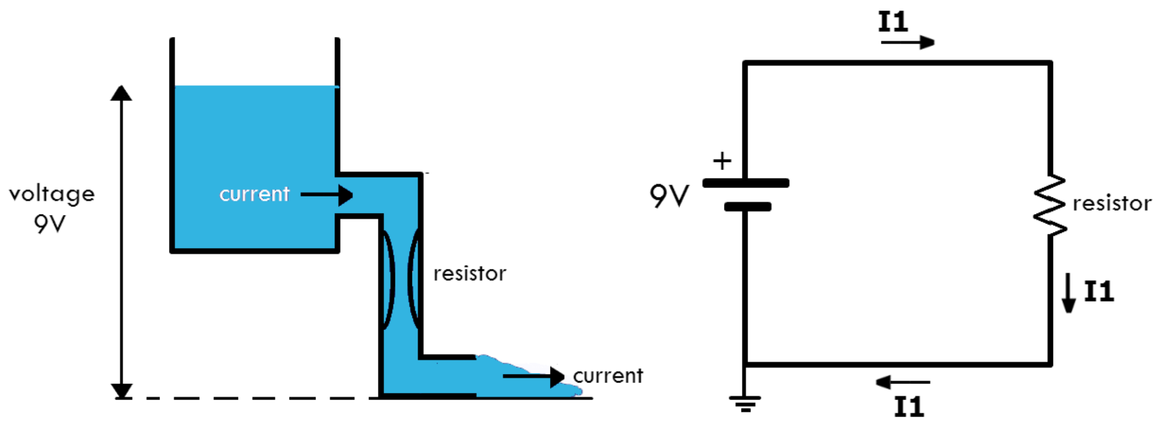
$$\therefore R = \frac{V}{I}$$

$$R = \frac{9V}{0.018A}$$

$$R = 500\Omega$$

In this example, one would most likely not be able to easily find a resistor rated at 500Ω, but instead 560Ω. The 560Ω can be substituted in. As one would imagine, overestimating the resistance is less likely to overflow the circuit than underestimating.

There is greater resistance in a long wire than a short wire due to a greater number of collisions with ions as electrons flow through the conductive wire. As the thickness of a wire decreases, the resistance also increases. This can be explained with the water analogy, for when you constrict the thickness of a pipe and pour in the same volume of water as before, there will be a higher "pushback" force. Thickness is measured by AWG (American Wire Gauge); the smaller the AWG number, the thicker the wire.

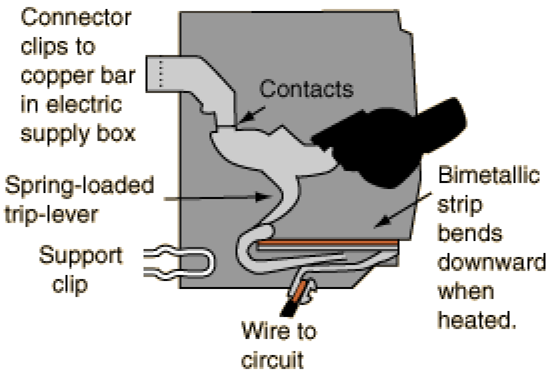


A resistor will work the same whether it is placed before or after a working object (e.g. LED) in a circuit, due to the fact that a circuit relies on a closed system of electron flow. To learn about resistance and its relationship with current and voltage at a greater depth, see this Wikipedia article about Kirchhoff's Circuit Laws. See this article for more information about resistors themselves.

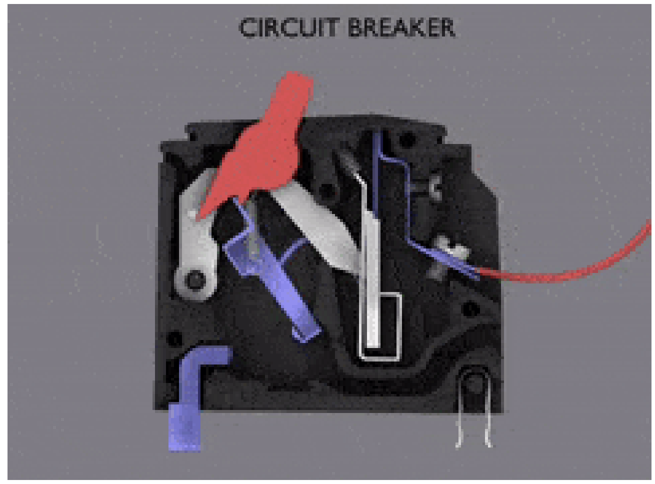
Fuses and Breakers

Fuses and breakers cap the amount of current - amperes - that is allowed to flow through a circuit.

In the FRC electrical system, we use a 120A main circuit breaker. These 120 amps will use friction between colliding electrons to heat a bimetallic strip. By heating the strip, it will bend and release the spring-loaded trip lever (see diagram below). In addition, since this heating will take time, if there is a large surge of current then a small electromagnet will push on the bimetallic strip in order to cut off the circuit. This is why we dubbed the main breaker the "kill switch" since it quite literally kills the flow of electrons by disconnecting a circuit.



This is a simplified mechanism.
the standard breaker has
several springs and levers.



There are also breakers used about the electrical system if you look closely. For example, the large ports on the Power Distribution Panel (PDP or PDB) need to be maintained by 40A breakers and the small ports require 30A breakers. More specifics about the placements of breakers can be found in chapters detailing the Standard FRC Electrical Layout.

What is the difference between a circuit breaker and a fuse? Both take advantage of the heating of conductive material in order to cap the amperes that can flow through a circuit. Fuses, however, are not reversible as circuit breakers are. Fuses can be made out of zinc, copper, aluminum, silver, and other metals, all rated at various melting points. If a circuit reaches that metal's specific melting point due to friction-induced thermal energy accumulation, then the fuse will blow (melt) and the circuit will be broken. As one would imagine, fuses only work when connected in series and not parallel. To see an animation of a working fuse, click this video link.

The Ground Wire

A ground wire connects a conductive material to the Earth, which is itself a reservoir of charge, independent from the circuit of an electrical appliance. The ground wire acts as a safety precaution in case of any fault in a circuit (due to wires bending, detaching, breakdown of insulation). Otherwise, 12V will travel through someone's body to the ground if they come into contact with this faulty circuit.

In FRC, GND is typically black, but in the U.S., it is not uncommon for GND wire to be colored green.

Safety Precautions

As always, Beavertronics takes safety precautions very seriously. We strive to support the learning of our students at a low level of danger, so that students can feel safe and comfortable in our shop. If you ever have a question about your degree of safety, don't be afraid to consult our Safety Captain or Safety Mentor.

Avoid working on an energized robot to not short the circuit with your own body!

- ❏ Power down the robot with the main breaker
- ❏ Unplug the battery
- ❏ Only do so if absolutely necessary, but with a Safety Captain and/or Mentor by your side

Basic Safety Electrical Requirements

- ❏ Inspect wires and extension cords regularly
- ❏ Never daisy chain power strips or extension cords (or one with the other!)

Battery Safety: Batteries contain corrosive sulfuric acid!

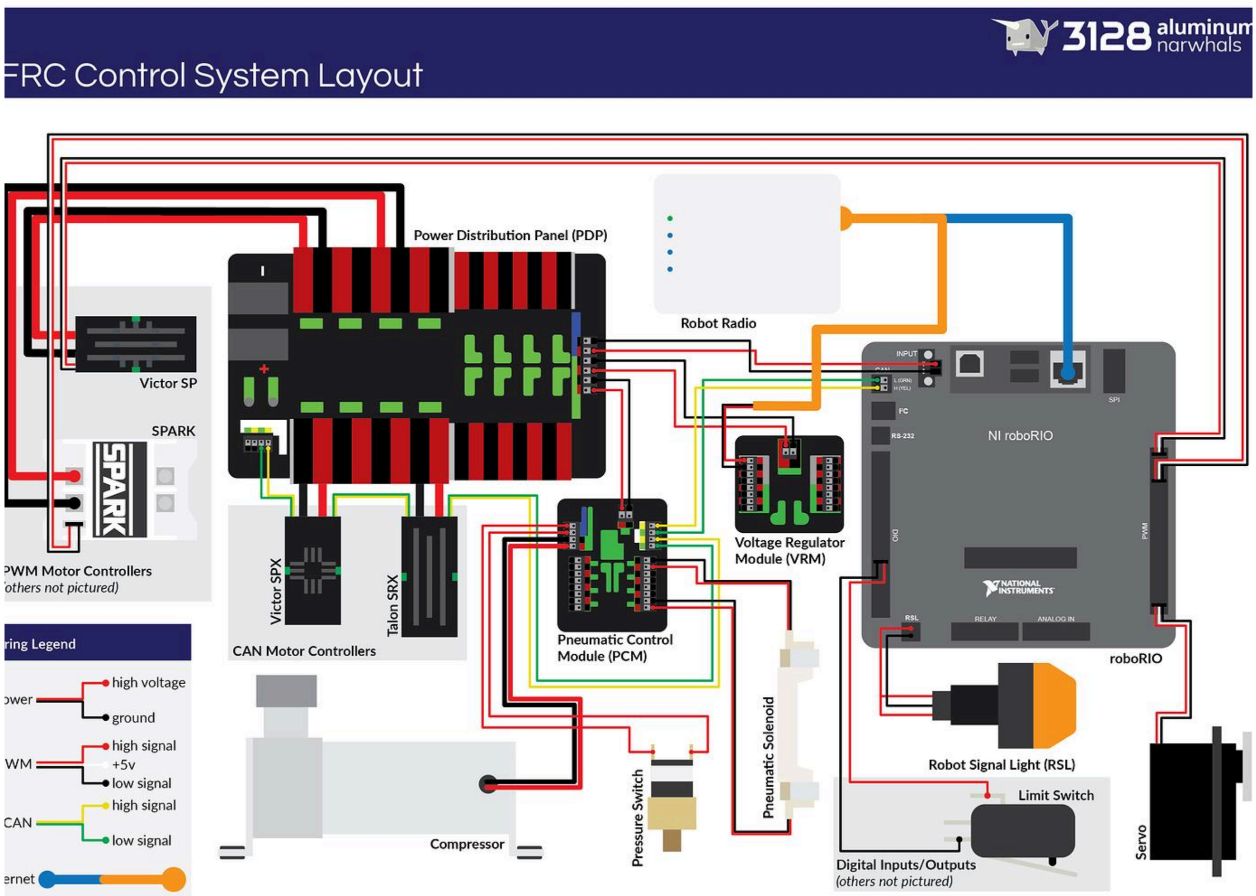
- ❏ Consult the Safety Data Sheet (SDS) if any spills occur
- ❏ Never use a battery that is visibly damaged or unstable in any manner. It could contain stored electrical energy.
- ❏ Know how to use the battery spill kit
- ❏ Routinely check the state of your batteries, including terminals

Soldering Safety Tips

- ❏ Use lead-free solder only
- ❏ No open flames; only use electrically-powered soldering guns
- ❏ Wear safety glasses
- ❏ Never touch the soldering gun nor the heat gun. Don't leave the hot tools where someone may accidentally touch them.
- ❏ Solder in well-ventilated areas
- ❏ Always wash hands after soldering
- ❏ Solder on a flame-resistant surface

Standard FRC Electrical Layout

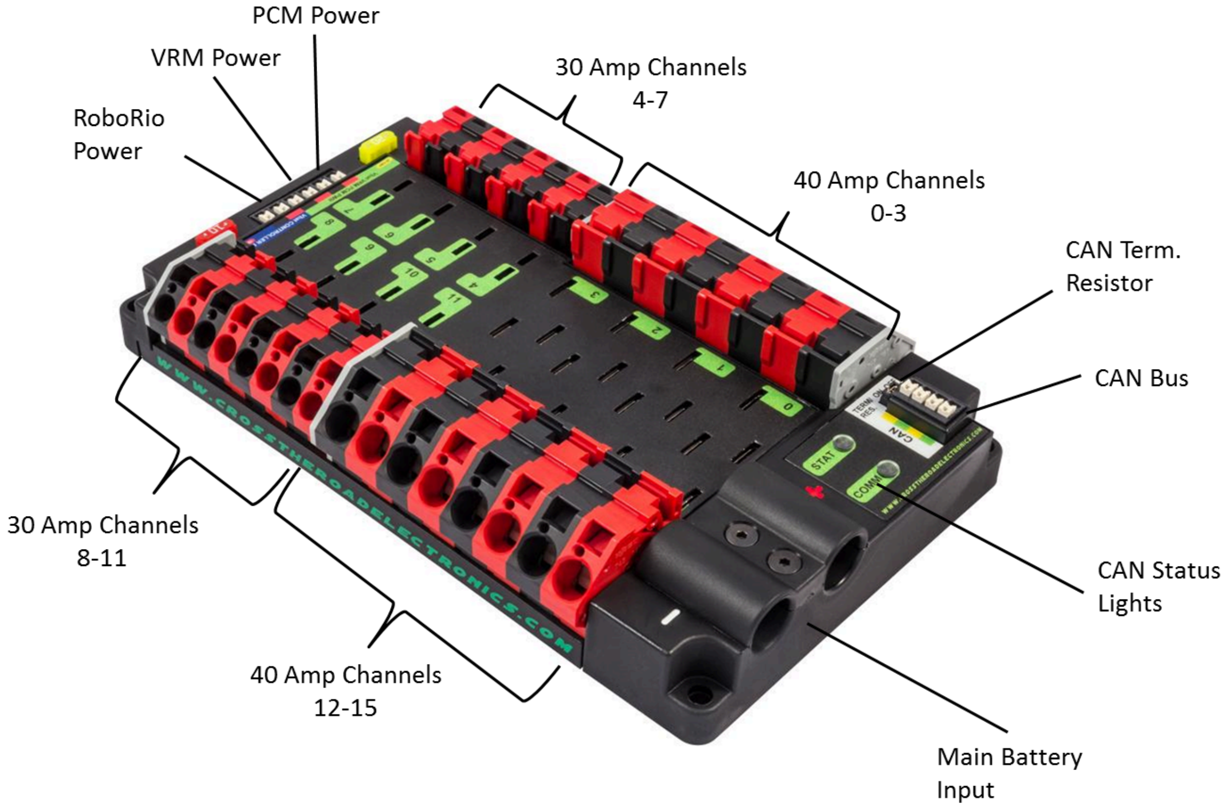
Although it helps to have a basic understanding of the electrical theory, FRC robots are usually wired about the same according to the following layout, with only minimal variation between different years' robots. The image below is according to 2019.



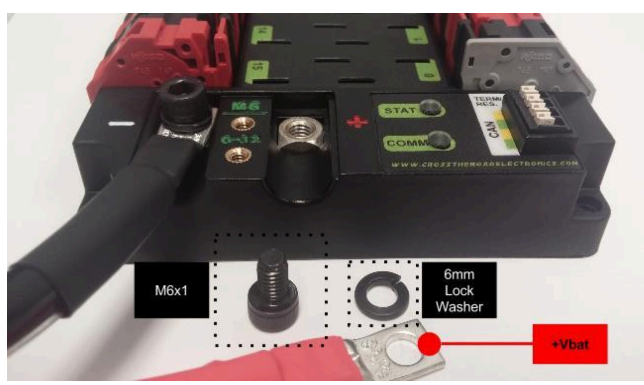
Power Distribution

Wiring the power supply for the robot is a good starting point for learning and understanding the FRC electrical system.

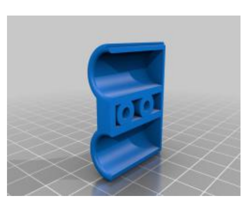
All power is first channeled from the 12V battery into the Power Distribution Panel (PDP; aka Power Distribution Board or PDB in past years). The name of the PDP is self-explanatory, as it does distribute power to motor controllers, the pneumatic control module, voltage regulator module, and roboRIO to allow them to do work using electrical energy. A labeled diagram of the PDP can be found below:



The 12V battery is wired as such, so that the two 6 AWG wires leading out of the picture on the left are connected to the battery terminals:



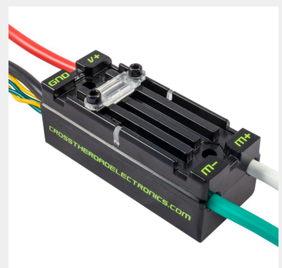
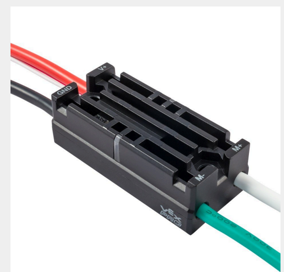
This piece is used to cover the battery terminal connection with the PDP:



Power distribution on the robot involves PWM, which stands for Pulse Width Modulation. To learn about what this means, watch this video! PWM is key to controlling output voltage directed to motors that will perform tasks for the robot. PWM is also highly important to understanding sensors, which will be elaborated upon further in Sensors.

Follow the circuit with me! From the main battery to the PDP to the motor controllers. Motor controllers come in many forms, but I will highlight the most relevant types:

MC names are linked with user guides	Victor SPX	Talon SRX	Victor SP
Dimensions	2.50” x 1.16” x 0.77”	2.75″ x 1.185″ x 0.96″	2.5″ x 1.125″ x 0.875″
Weight (Without Wires)	0.12 lb	0.19 lb	0.16 lb
Communication Protocols	PWM, CAN	PWM, CAN. SPI, USART (serial)	PWM
Direct Sensor Input	No	Yes	No
Nominal Voltage	12V	12V	12V
Min / Max Voltage	6-16V	6-28V	6-16V
Continuous Current	60A	60A	60A
Surge Current (2 sec)	100A	100A	100A
PWM Input Pulse (high time)	1-2 ms nominal	1-2 ms nominal	1 - 2 ms nominal, 0.6-2.4 ms max
PWM Input Rate (period)	2.9 - 100 ms	2.9 - 100 ms	2.9 - 100 ms

PWM Output Chop Rate (Switching Frequency)	15 kHz	15 kHz	15 kHz
Minimum Throttle (Deadband)	Adjustable 0.1% - 25% (4% Default)	Adjustable 0.1% - 25% (4% Default)	4%
PID Control	Limited; No constant current	Yes; Onboard algorithms	No
			

Many teams also take advantage of the SPARK motor controllers provided by the kit of parts. To learn more about these controllers, visit this website. On Beavertronics, we have discovered that programming SPARKs using Python has proven to be quite challenging, so we typically steer clear of these bad boys.

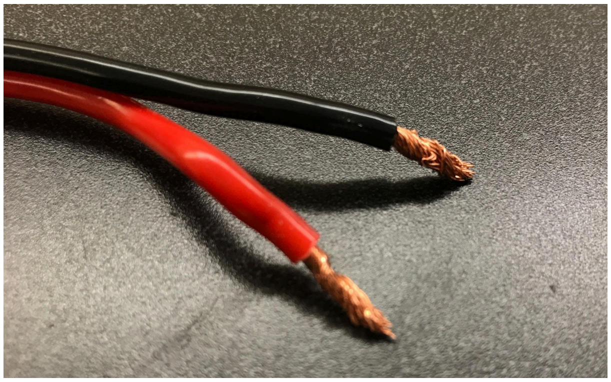
Some common features of these three described motor controllers include:

- Inner cooling system (fans are optional)
- Lights blink proportional to duty cycle (output speed)
- Completely sealed
- Insulated components. Mount to drive base without fear of shortage
- Mounted with bolts (pockets for #8 nuts on Victor SP and Talon SRX)
- Use LEDs to signal functionality

Elaborating more on LED signals, different colors are intended to communicate different statuses.

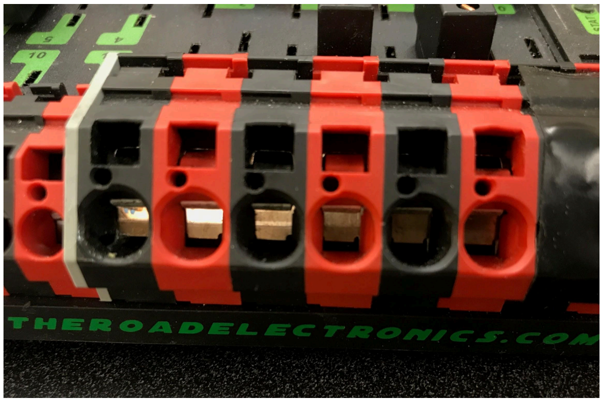
Model	LED color	Status
Talon SRX & Victor SPX	Flashing Red/Green	Ready for calibration; flashing color that follows indicates success
	Both Blinking Green	Forward throttle (output voltage = input voltage)
	Both Blinking Red	Reverse throttle (output voltage = input * -1)
	Alternating LEDs: Off/Orange	Disabled bot, CAN detected
	Alternating LEDs: Off/Slow Red	CAN/PWM not detected
	Alternating LEDs: Off/Fast Red	Fault detected
	Alternating LEDs: Red/Orange	Damaged hardware
Victor SP	Flashing Red/Green	Ready for calibration; flashing color that follows indicates success
	Solid Green	Forward throttle
	Solid Red	Reverse throttle
	Blinking Red or Green	Any abs[throttle] < 100%
	Solid Orange	Enabled but within 4% deadband state
	Blinking Orange	Disabled; PWM signal lost

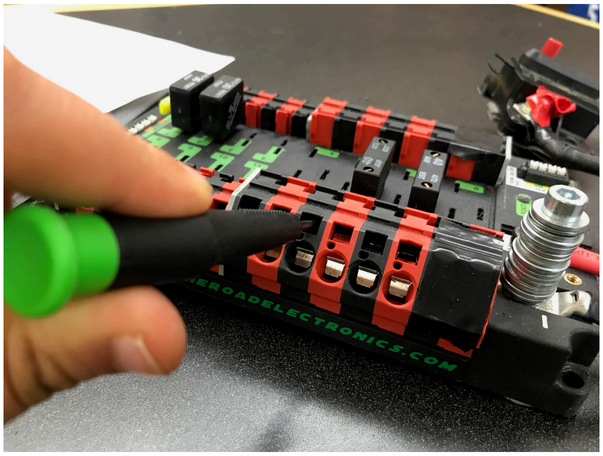
Notice that there are two types of channels, 30A and 40A, from which one can route motor controllers. Plug in a breaker corresponding with both the amperage and placement of the motor controller (channel #). When plugging motor controllers into the PDP, it is recommended that you use a ⅛ flat head screwdriver to depress the tongue above the channel.



Twist the 12AWG wires. This will make your job easier when fitting the wire into the PDP channels.

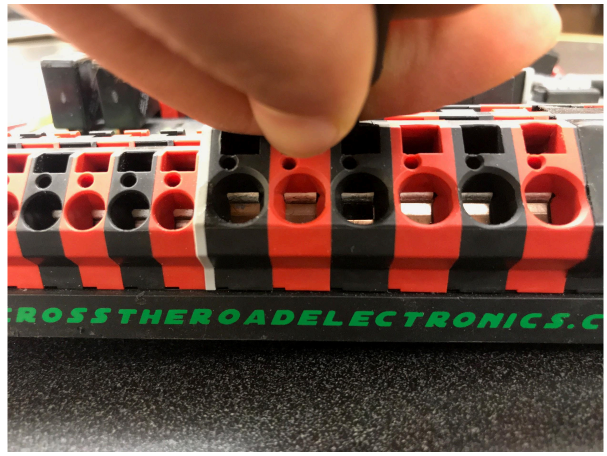
These are the PDP channels where you insert the 12AWG motor controller wires. Notice that there are two sections to the channel: a tongue on top and a crimper ("mouth").

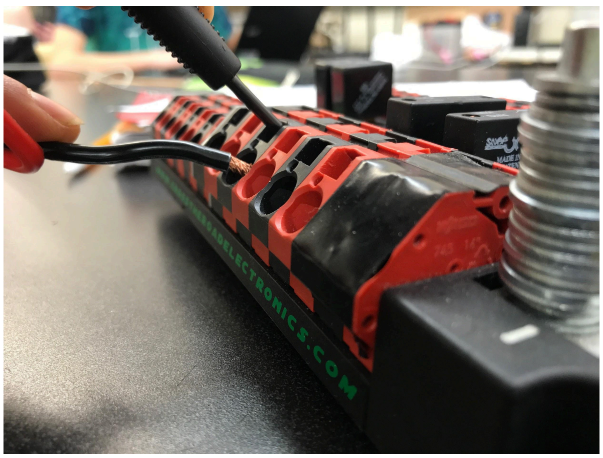




Use a ⅛ flat head screwdriver to depress the tongue on top of the channel in which you intend to insert the 12AWG wire.

When you depress the tongue then the mouth will go “ahhhhh”. Ready to bite!





You must insert the wire while holding the screwdriver firmly down. This will take trial and error, as the screwdriver slips easily, but comes with practice.

Once you remove the wire from the mouth of the channel, if the connection was secure, then it should be crimped as such.

Follow the circuit with me, again! From motor controllers to the motors themselves. In FRC, there are four key motors that one should be familiar with. All function with DC power.

- CIM
- Mini-CIM
- 775pro
- NEO brushless

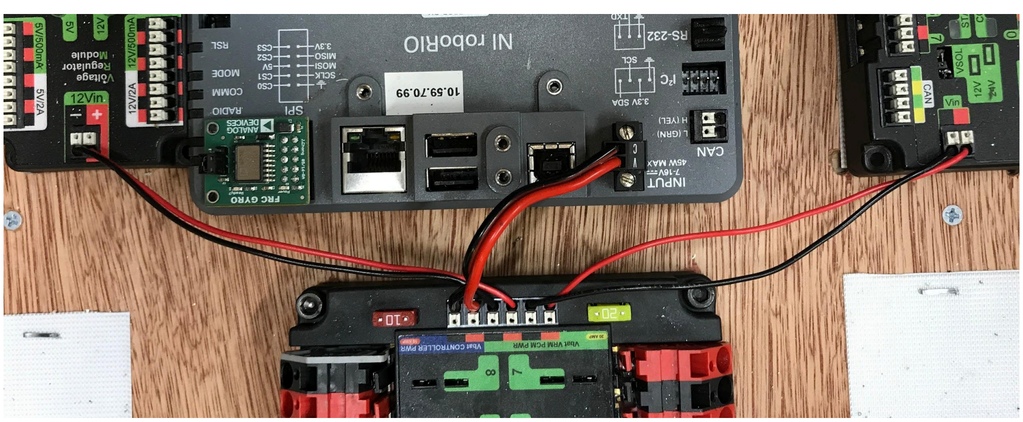
To learn more about motors, watch these videos and visit this website.

Motor names are linked →	CIM motor	Mini-CIM motor
Weight	2.8 lbs	2.61 lbs
Size	2.5”	2.5” diameter; 3.36” long
Battery In	12V	12V
Output Shaft	8mm with 2mm keyway	8mm with 2mm keyway
Free Speed	5 330 rpm	5 840 rpm
Free Current	2.7A	3A
Max. Power	337 W	215 W
Stall Torque	2.41 N-m	1.4 N-m
Stall Current	131A	89A
		

Motor name is linked →	775 pro motor	BAG motor
Weight	about 0.8lbs (varies with model)	0.71 lbs
Battery In	12V	12V
Output Shaft	5mm	4mm
Free Speed	18 730 rpm	13 180 rpm
Free Current	0.7A	1.8A
Max. Power	347 W	149W
Stall Torque	0.71 N-m	0.4 N-m
Stall Current	134A	53A
		

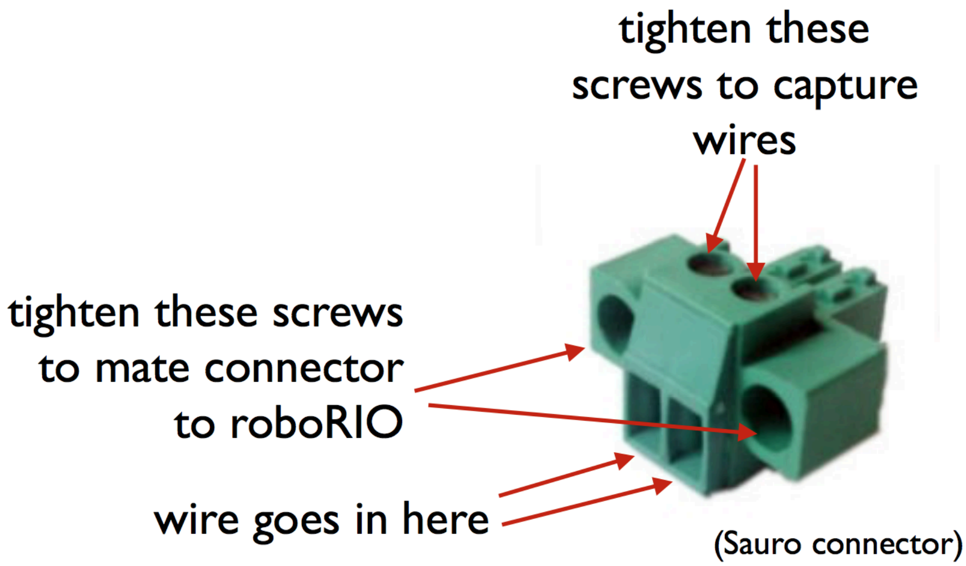
Motor name is linked →	NEO brushless motor	Falcon 500 motor
Weight	0.938 lbs	1.1 lbs (without wire)
Battery In	12V	12V
Output Shaft	8mm	Interchangeable
Free Speed	5 676 rpm	6 380 rpm
Free Current	1.8A	1.5A
Max. Power	406 W	783 W
Stall Torque	2.6 N-m	4.69 N-m
Stall Current	150A	257A
		

To finish our discussion about power distribution, we must (unfortunately) backtrack throughout the circuit a bit to the PDP. From the PDP, power is directed into the VRM (Voltage Regulator Module), PCM (Pneumatics Control Module), and roboRIO; then these modules perform their own duties and also control electric flow towards the desired output. See the photo below for a close-up image of these connections:

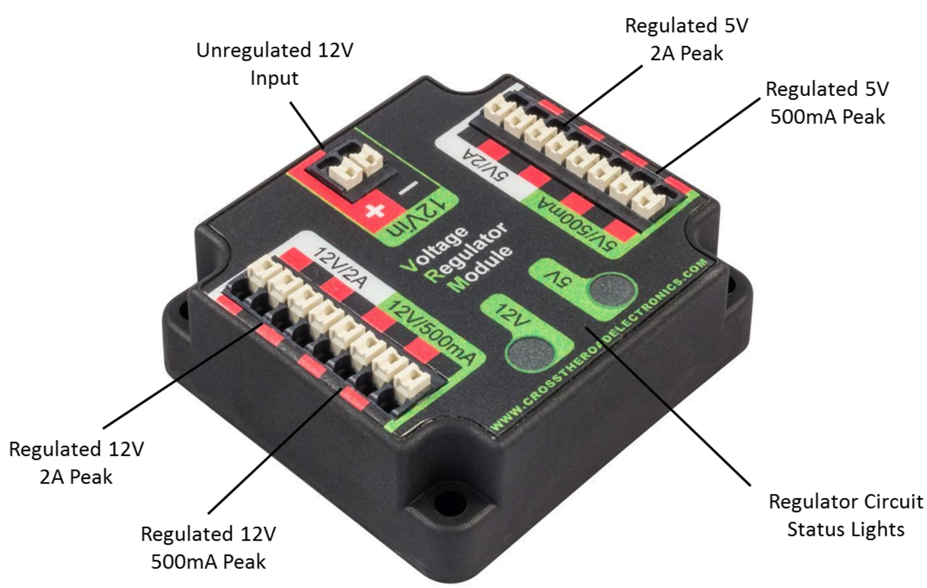


Although the small yellow and red pieces at the end opposite of the main battery input appear to be breakers, do not be fooled! These pieces are 20A and 10A fuses respectively. Keep this in mind, for if one of the fuses blows, it cannot be reused.

The wire connecting the __ and the __ requires a __ flathead screwdriver. Follow the picture sequence below for further instructions:

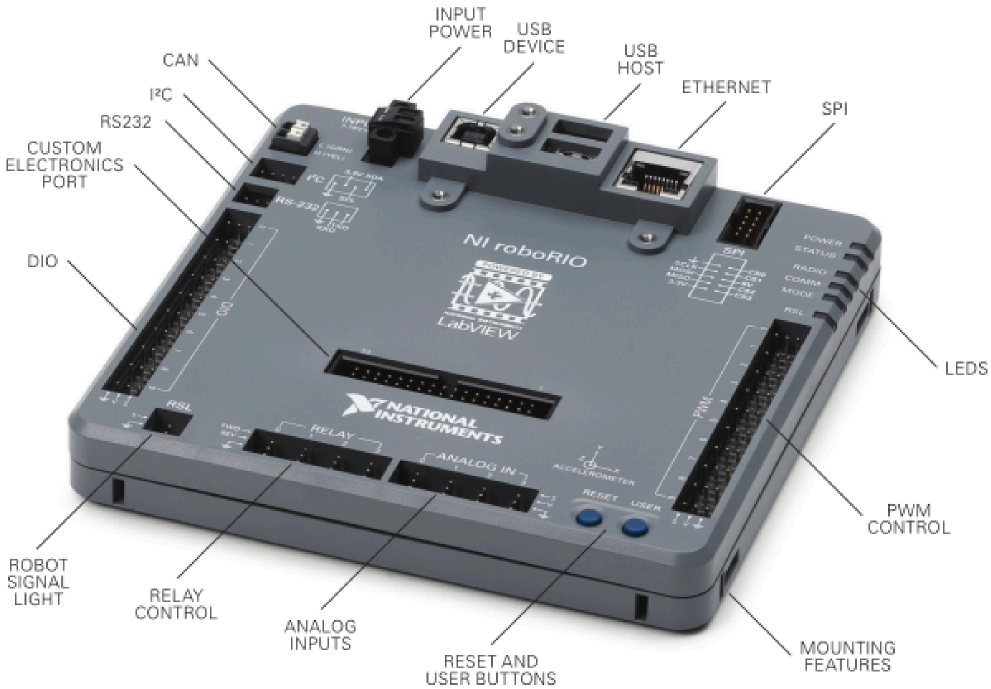


The VRM is powered by 12V channeled through the PDP. Its purpose is to regulate voltage into 12V and 5V outputs for the purpose of powering the robot radio, custom circuits, and IP vision cameras. Do note that each connector pair is labeled with different amounts of current draw; although, one should never draw the maximum current from the corresponding VRM port.



Signaling Devices

The NI roboRIO is essentially the brain of the robot; code is deployed to the roboRIO and commands the PWM, DIO, RSL, analog inputs, relay controls, USB, SPI, etc. via the ethernet cable.



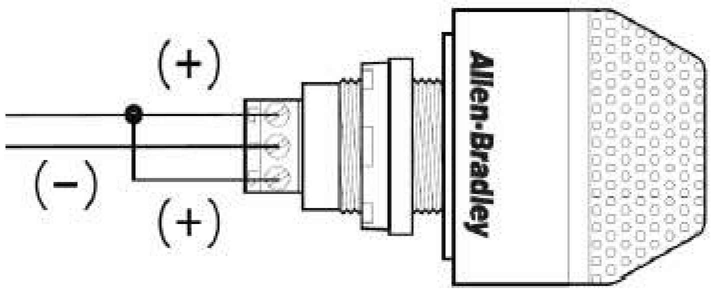
DIO stands for Digital Input and Output. DIO commands and connects to sensors on the robot that interpret data from the outside world. Another common type of sensor is Analog In, represented by a continuously oscillating graph, that itself represents physical properties with a variable voltage. Sensors are often also connected to SPI (e.g. gyro) or the custom electronics port. For electrical parts previously undealt with by the team, consult their user manuals for connection details.

In the past, Beavertronics has also implemented a Jetson TX1 for additional processing capabilities required by vision. Here are some documentation resources specific to the Jetson:

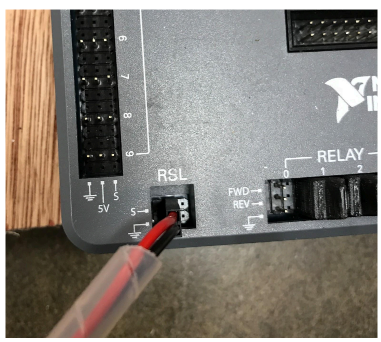
Optimal Input Power Voltage
Helpful Chief Delphi Thread

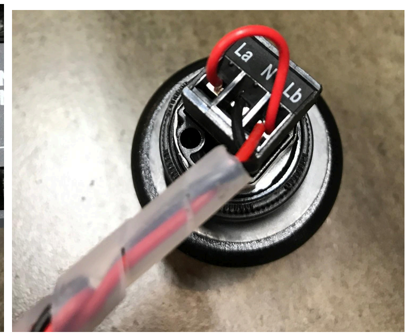
Do note that the Jetson TK1 is included with the Kit of Parts and can be obtained with FIRST credits.

The RSL, or Radio Signal Light, signals to the drive team the status of the robot.



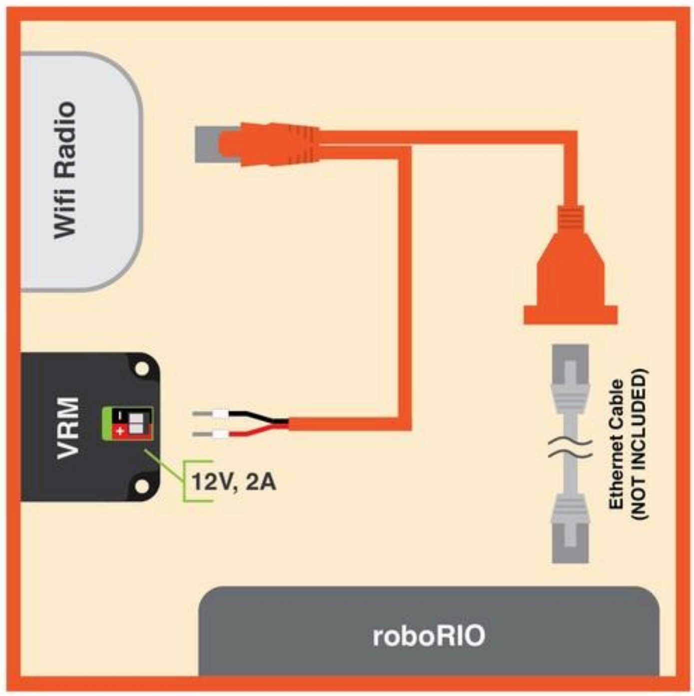
Light Signal	Status
No light	Robot powered down
Solid light	Robot disabled
Flashing light	Robot enabled





The FRC robot radio sends and receives wireless signals to the programmed driver station, acting as a WiFi bridge. The 2017 radio and succeeding models appear as follows:

In order to power the radio, __AWG wire must be routed from the 12V/2A port on the VRM in order to power the radio using a PoE injector cable, which plugs-in to the 18-24vPOE port on the radio and the male end of an ethernet cable routed to the roboRIO. This is illustrated below. PoE stands for Power over Ethernet. This is a passive cable that combines the electrical current of both the power and signal wiring, which would normally stand alone.



When using the orange PoE injector cable, one must always insert an ethernet "middleman" cable into the female end of the PoE.

Although the model is outdated, follow the diagram below for understanding LED signals from the robot radio:

Power	
Blue	On or Powering Up
Blue Blinking	Powering Up
Eth Link	
Blue	Link Up
Blue Blinking	Traffic Present
WiFi	
Off	Bridge Mode, Unlinked or non-FRC firmware
Red	AP, Unlinked
Yellow\Orange	AP, Linked
Green	Bridge Mode, Linked

WiFi light only works after radio has been power cycled.

To configure the radio for events outside FRC competitions, use the configuration system available on your current season's control system page on the FIRST website. The link to radio configuration should be under "Programming your radio". For example, 2019 Deep Space students referred to the following link:

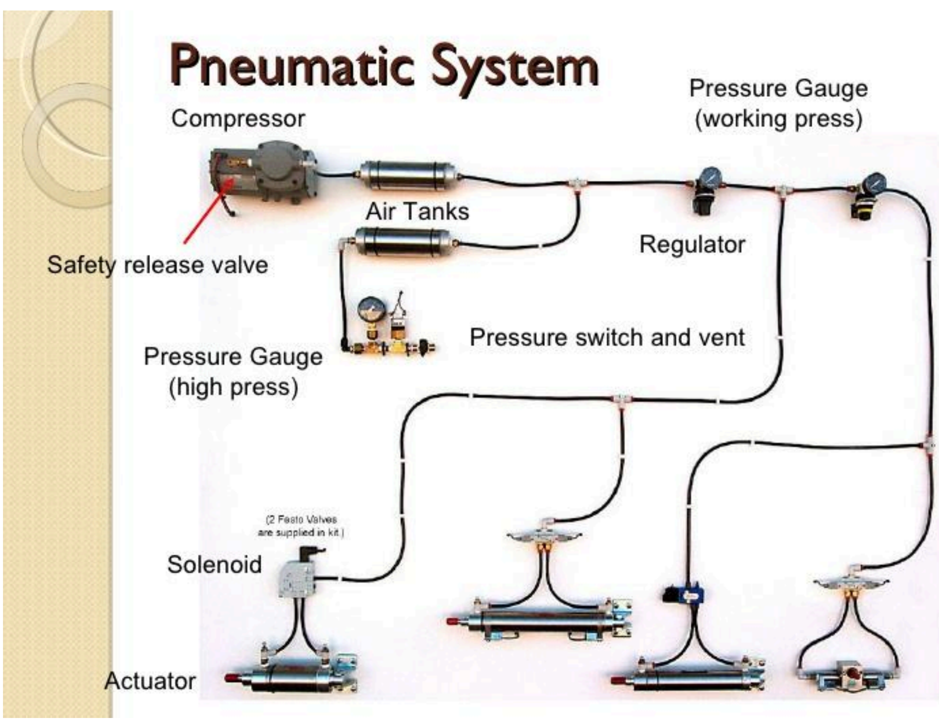
FRC Radio Configuration 19.1.1

Follow all steps on the configuration key as well as those under "Programming your radio".

Pneumatics

Pneumatics is the technical term for transforming air pressure into linear motion using pneumatic pistons and compressed air. A pneumatic system is comprised of the following parts:

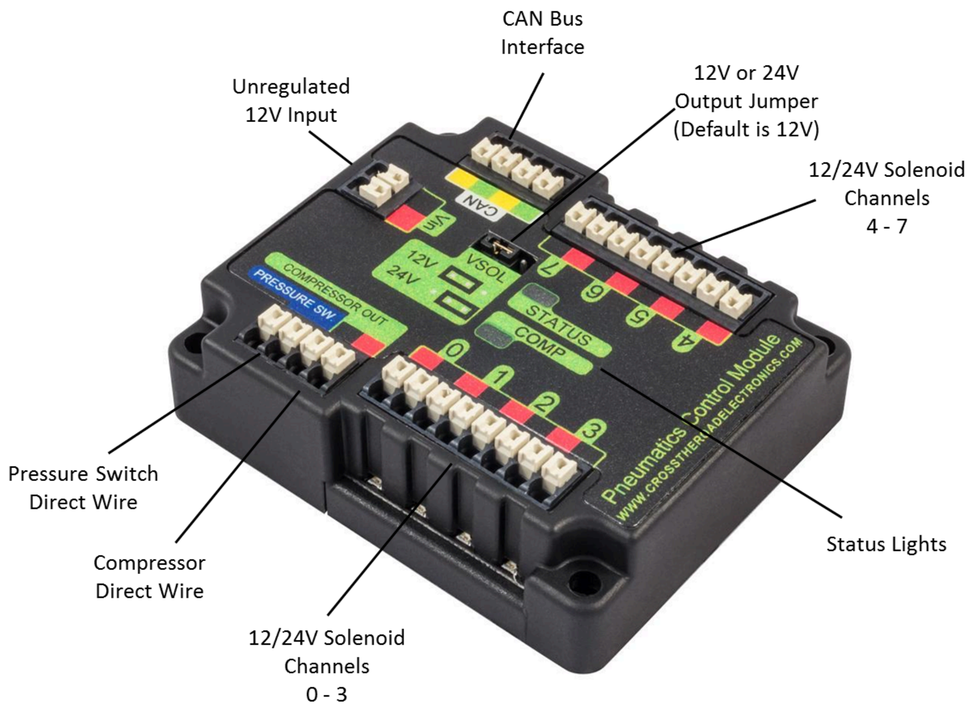
- Compressor
- Switch
- Safety Release Valve
- Air Tank
- Pressure Gauge

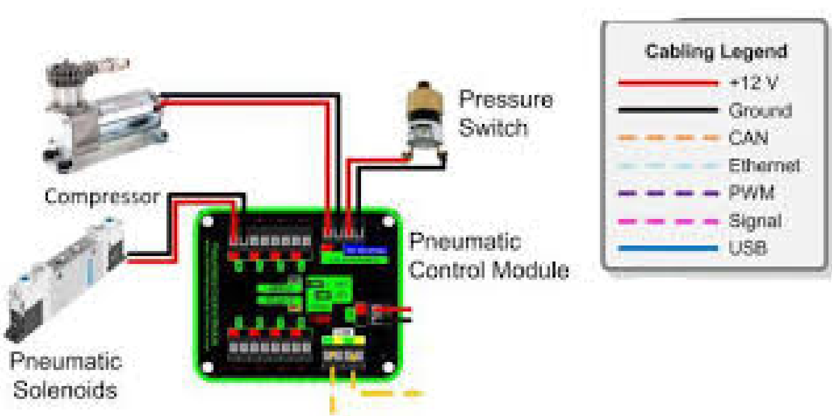


To learn about each part of a pneumatic system in greater detail, visit this document.

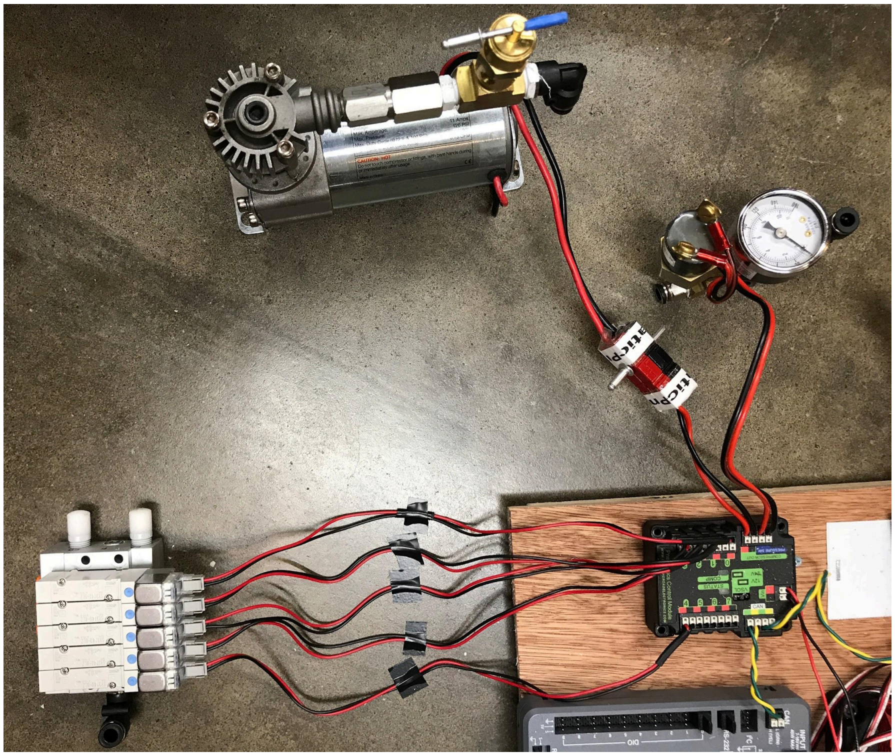
Clippard's introduction to pneumatic air systems provides excellent explanations and diagrams. Pneumatics is quite similar to electric circuitry in that compressed air moves according to a current, satisfying the direction of flow according to potential difference. Not to mention, pneumatic systems result in an "on/off" output signal -- that is, actuated or retracted piston. Pistons used in FRC are regularly either spring loaded (thus actuated outwards when normal atmospheric air pressure is applied) or double-action pistons (see Clippard's diagrams).

These pneumatic systems are wired to the robot control system via the Pneumatic Control Module, or PCM, depicted in the image below.

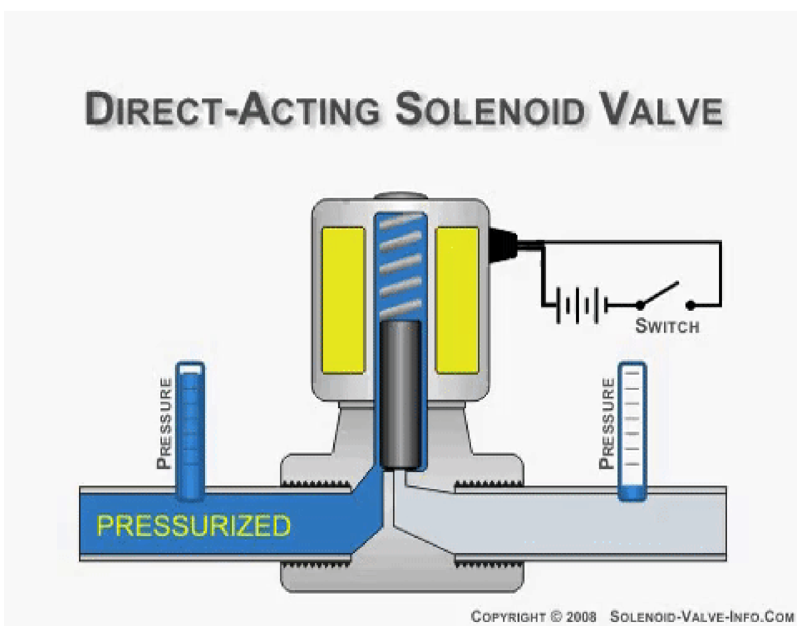




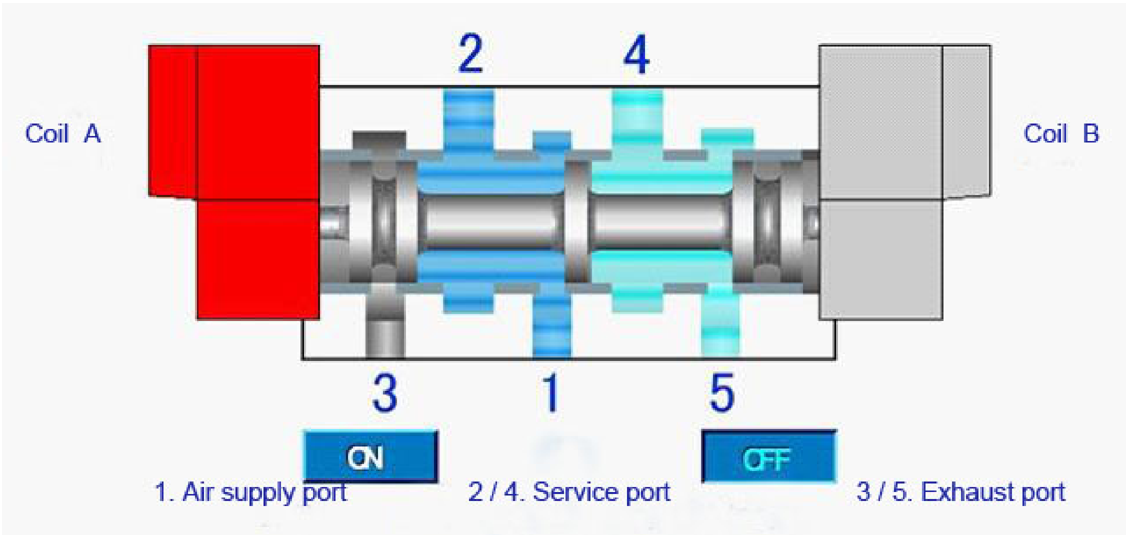
The solenoid typically used by Beavertronics is a double-action solenoid with 5 valves. The wiring from our 2019 robot "Oowa" from the solenoid to the PCM appears as follows:



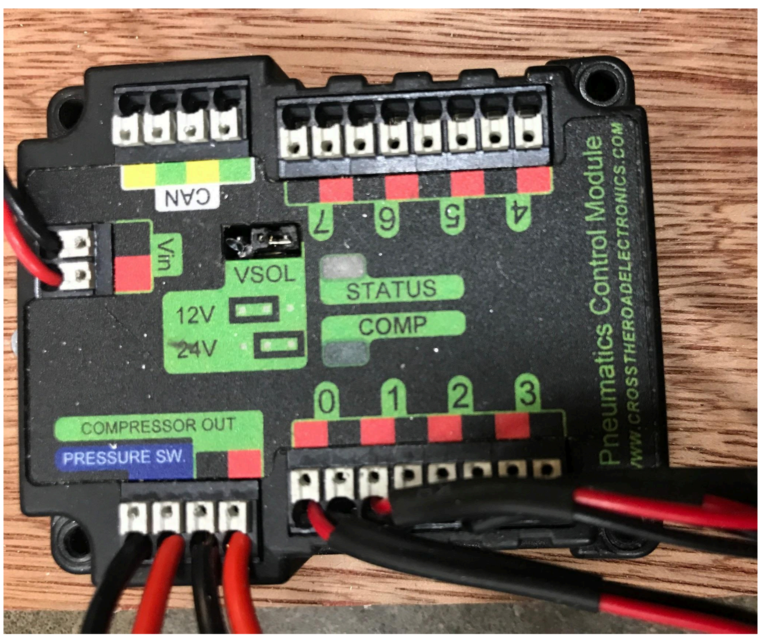
Solenoids work by directing the direction of air flow after receiving electrical signals. Throughout our recent years, we have used five solenoid valves, as depicted in the images.



Do note that the diagram above does not exactly reflect how our solenoids function. Instead of simply blocking off the path, air is instead directed into a second path, as exemplified in the diagram below. (The image above serves more of a conceptual than specific purpose.)



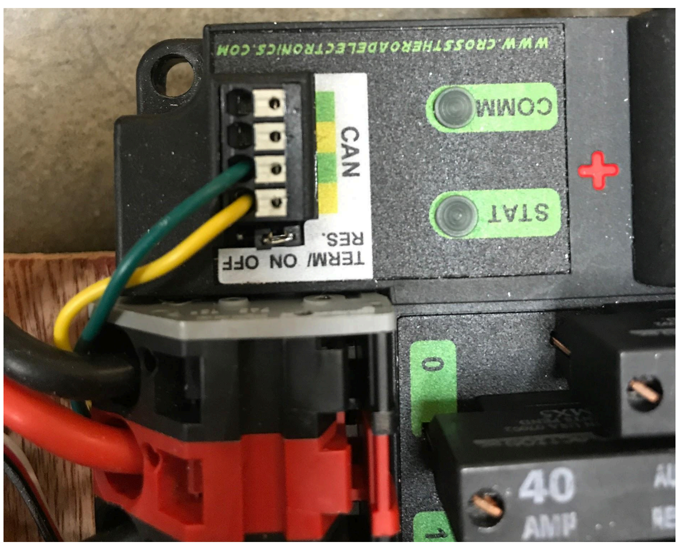
Beware, though, dear programmers. For the solenoid valves are misaligned with the PCM values by one; solenoid 1 connects to port 0, solenoid 2 to 1, etc. This is if the following configuration is kept (you may wonder why we don't simply move the wires over one... we tell ourselves it's so we can maximize the number of available ports so that we're able to sleep at night). Since programmers only care about electrical, they will only care about the PCM values.



CAN Bus

CAN stands for Controller Area Network. This name makes sense once you realize the purpose of the CAN bus: to serve as a bi-directional line of communication between multiple devices. Instead of simply sending "signals" between devices, the CAN system can transfer information, such as raw data. The roboRIO from 2015 and onwards have a CAN system built-in; other devices such as the PDP, PCM, and certain motor controllers also take advantage of CAN wiring.

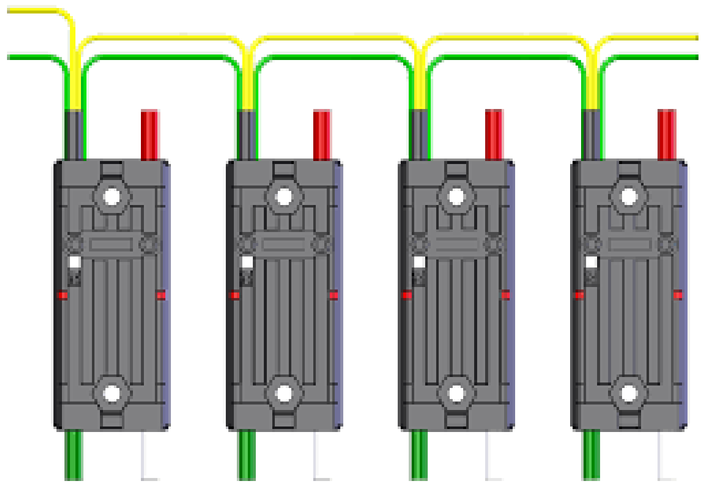
Each end of the CAN bus must be located at a terminal. Typically Beavertronics terminate the CAN bus at the roboRIO and PDP since these ports have built-in termination resistors (120 Ω). (see images below)

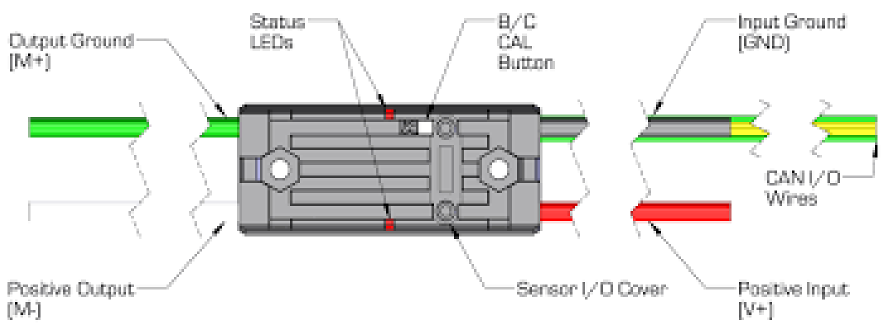


The CAN bus wires are yellow and green 22 AWG wires. The green wire serves as a ground wire.

When wiring the Victor SPX, the CAN bus can be chained in the following manner:

When wiring the Talon SRX motor controllers, follow the following diagram:





Using CAD to Model the Electrical System

Modeling the electrical system is important so that the design and build subteams remember that the electrical team exists. (Somehow, they conveniently forget that none of their mechanisms can work without us. Funny how that works.) We will first go through the most basic form of modeling the electrical system -- with rectangular prisms and color-coding! Why sink to such a lowly level of modeling? It saves space on your computer and it saves your brain from turning into spaghetti. (Fun fact: The CAD crew are all walking zombies.)

First and foremost, the most important part of modeling the electrical system is documentation. Take pictures and write helpful captions so that you can keep track of mistakes made, and thus, how to avoid repeating those mistakes in the future. In this documentation, remember to write a succinct summary about the main learning points so that other teammates can access your work as a quick reference.

For more elaboration on the importance of electrical documentation, visit this link.

As a quick reference, here are the dimensions for all the key devices of the electrical system:

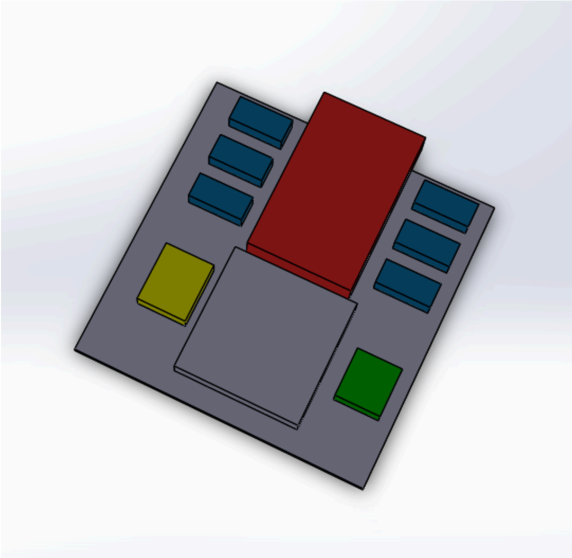
Device	Length	Width	Height	Number	Color
RoboRIO	146.15 mm 5.754 in	143.18 mm 5.637 in	20.91 mm 0.823 in	1	
PDP	192.68 mm 7.586 in	120.88 mm 4.759 in	36.15 mm 1.423 in	1	
PCM	69.09 mm 2.720 in	56.90 mm 2.240 in	19.67 mm 0.774 in	1	
VRM	56.39 mm 2.220 in	51.56 mm 2.030 in	19.92 mm 0.784 in	1	
Motor Controllers	2.5 - 2.75in*	1.125 - 1.185in*	0.77 - 0.96in*	6-8*	

*varied, check robot specifications

The dimensions provided are the maximum values (e.g. PDP width and height are in regards to the 40A ports, which stick out more than the 30A ports). Even still, it is best to round the dimension values up to the closest ¼ inch value to give yourself that extra bit of wiggle room.

As a keynote, if assigned the task of laying out the electrical system on CAD, always check with the electrical subteam lead before sending it off into the void that is the CAD crew. This is to verify that the spacing is realistic since the subteam lead has had at least one season's worth of experience working with the devices; to avoid exposed wire, a fire bot, and a screeching safety inspector, devices should not be uncomfortably close; nor should they be a mile apart. :)

CAD is very useful for mapping out the electrical system especially when one is forced to be creative with spacing; if planning a multilevel electrical system or creating unique wire routing, CAD is a cool tool to take advantage of!



Alternatively, you can download the CAD files off of the VEX or AndyMark pages specific to the respective model. While this will result in a more accurate representation, it will also consume more space on your computer. (And, to be quite honest, the CAD crew could care less about these minor details, unfortunately.)

SOLIDWORKS Electrical is mainly useful for custom electrical parts. Most robots will not require this level of advanced sorcery to compete effectively and successfully. If necessary, however, here is a SOLIDWORKS Electrical overview of fundamentals.

AWG Guide

Subsection of Electrical System	Point A	Point B	Gauge Used (AWG)
Power Distribution	120A breaker	PDP Main Battery Input	6
	PDP 40A channels (0-3; 12-15)	Motor Controllers	12
	PDP 30A channels (4-7; 8-11)	Motor Controllers	12
	Vbat VRM	12Vin on VRM	
	Vbat VRM	Vin on PCM	
	Vbat Controller	RoboRIO INPUT 7-16V	18
CAN	CAN Termination Resistor on roboRIO	CAN Termination Resistor on PDP	22
Signaling Devices	Sensor	DIO ports	22
	Motor Controllers	PWM ports	22
	Camera	USB port	--
	RSL	RSL or RSL roboRIO port	22
	Ethernet	Ethernet	--
Pneumatics	Compressor Out	Compressor	18
	Pressure SW	Pressure Switch	18
	PCM ports 0-7	Solenoid	22
VRM	5V/2A	Radio	-- (POE)

Sensors

Sensors are devices that measure physical properties. These measurements can be recorded in order to result in some output function, which can be a digital or physical response. On FRC robots there are three main opportunities for feedback for which one may use a sensor:

1. Detecting field elements
2. Positioning robot parts
3. Motion control

Beavertronics primarily uses boolean sensors, which connect to DIO on the roboRIO, which typically involve the easiest implementation. There also exists analog and digital serial sensors. Analog sensors have a tendency towards imprecision but also record and deliver more information. Digital serial sensors are more precise with higher resolution, but of course, involve the most complex implementation.

While we are discussing implementation, wires should almost always be connected to sensors with connectors instead of solder; I learned this the hard way. See the picture below for concrete evidence:

Detection of Field Elements

Under the three purposes for sensors, cameras, vision, limit switches, and proximity and beam breaks would qualify as detectors of field elements.

Cameras

In Deep Space 2019, there was a 30-second sandstorm period. This was a crazy time to be alive because the driver and operator could actually touch the controls, a task made easier by using a camera. Of course, the OP teams (@frc2056) still had vision control that they used in autonomous, but we were not that advanced (yet).

The camera we used was ___ and it connected to the USB port on the roboRIO. See the picture sequence below:

IP cameras -- routed to the VRM -- can also be used. IP cameras will send images wirelessly over wi-fi signals. Check voltage specifications to know where to hook it up from the VRM.

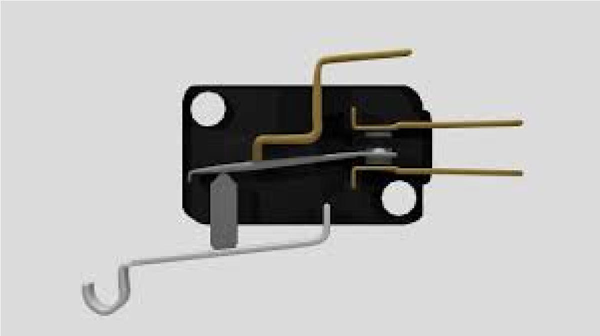
Other Vision

Teams often use a ring light to create reflection off the vision tape; this simplifies lining up and positioning robot parts in accordance to the field. Read more about target retroreflection and processing targets if you're interested -- our team has not yet had hands-on experience with these strategies (once we do, updating this manual will be essential for documentation purposes).

Teams such as the Cheesy Poofs or Code Orange used Limelight for their vision system. See this link for further information about the Limelight device.

Limit Switches

The image above depicts a limit switch. The name “limit switch” accurately describes its function: a binary switch that produces boolean values (True/False). Either the switch is pressed, or it isn’t. To change the “normal state” of the switch, wire it to either be normally open or normally closed. That is, if the triggering event is when the switch is pressed, then one would solder the 20-24 AWG power wire to “NO” or “normally open”, and vice versa.



Limit switches can be used to detect field elements such as if the robot has collided with a field element or another robot. One must take caution, however, for limit switches are notorious for false signaling and for low durability. If a limit switch is compressed with excessive force too many times, it will stop working properly. If the limit switch does not have enough resistance in switch compression, it can compress due to unavoidable shaking of the robot as it drives, which can send false triggers.

Alternative Options

Proximity and Beam Break

Ultrasonic Range Sensors

Positioning Robot Parts

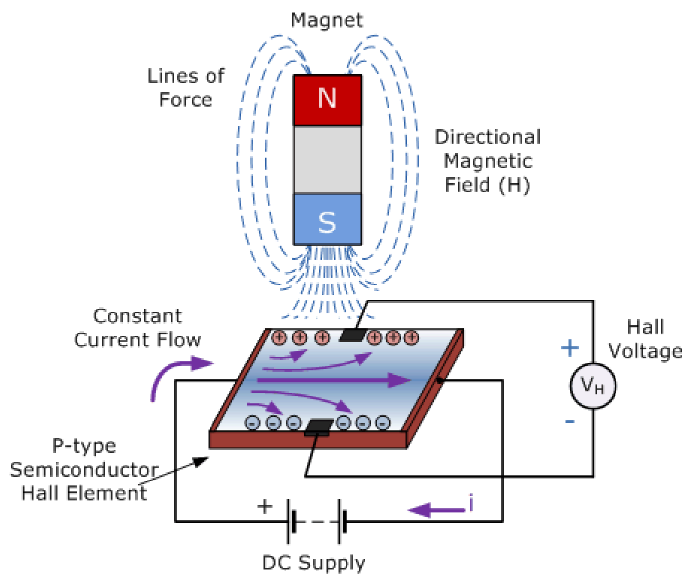
Limit switches, hall effect sensors, and potentiometers work well when positioning robot parts.

Limit Switches

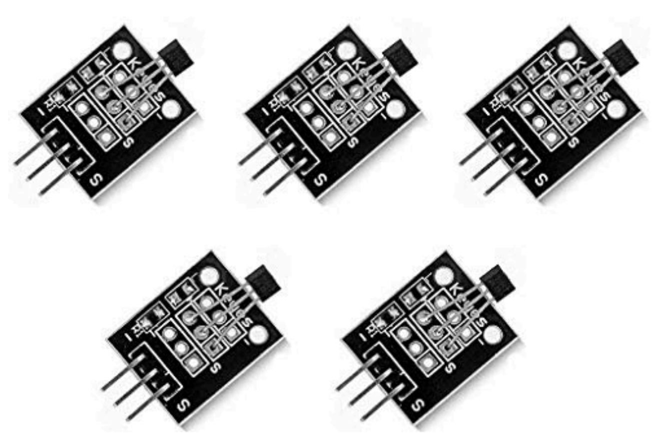
Refer to description above. Instead of the triggering event taking place from the field elements, the switch will be triggered by an event inside the robot. For example, our Deep Space robot initially was designed with an arm jointed in the middle, low interior of the superstructure. In one position, cargo and hatches could be loaded, the arm would flip, and in position two, game pieces could be scored. Given that the arm was either in position one or two, one limit switch was placed on either end so as to signal the position of the arm and to calibrate the magnetic rotary encoder being used to track the arm.

There also exists the rotary limit switch, which will track rotational position. For example, they can stop motors from turning beyond a certain point. See this Chief Delphi thread for more information.

Hall Effect Sensors



The most common hall effect sensor used in FRC is the hall effect switch. This essentially acts like a limit switch but instead takes advantage of magnetic fields.

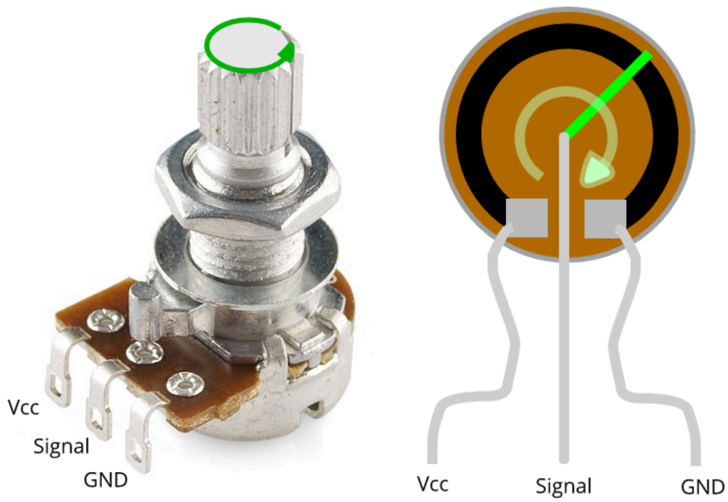


To use a hall effect switch, simply place a magnet on the desired part to be sensed, and once the sensor detects the magnetic field at a certain proximity, a boolean value will be produced indicating "True". For example, if using a hall effect sensor to indicate the position of an elevator, sensors could be placed on either end of the elevator while a magnet fixed onto the second stage would move up and down, triggering one of the hall effect sensors at a time.

While Beavertronics has never used hall effect sensors, here are some possible resources that provide the product at an affordable price: REV Robotics, 971 Spartan Robotics with WCP

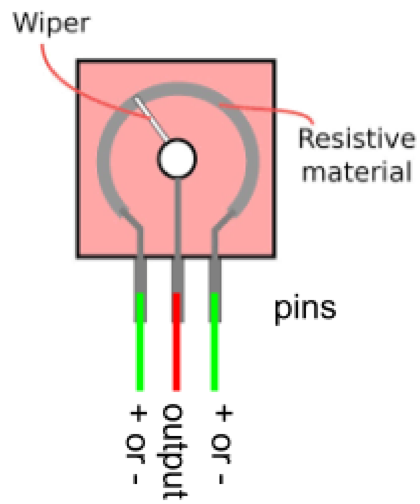
Hall effect sensors can also be used to measure rotational speed of mechanisms, although the set-up is slightly different. A magnet is fixed behind the sensor, which sits between the magnet and the rotating shaft. On the shaft is a wheel; when the wheel spins on the shaft, the teeth and crevices create square waves as they pass by the hall effect sensor, as modeled in this video.

Potentiometers



Potentiometers are a type of absolute rotary sensor that uses resistance to track the physical property position. Ring a bell? This is an analog sensor, since by varying resistance, it in turn varies voltage. How does the potentiometer accomplish this?

This animation does a wonderful job of breaking down the concept. In short, though, a "wiper" turns along a resistor which will modify the length of the resistor, thus varying resistance in ohms. Based on the position of the wiper, which will output a certain voltage due to resistance, the RoboRIO can determine the rotational position of the potentiometer. See the wiring diagram below (although the image above specifies GND, the left and right-most leads are interchangeable):



Also note that potentiometers are absolute encoders, meaning they know the exact position. This does mean they have a limited range. Contrast this to incremental encoders discussed later on.

Motion Control

Motion control is the most sensor-heavy part of the FRC robot. Sensors are detrimental to the accuracy and reliability of a manipulator. In previous sections, primarily drive base positioning has been discussed -- but now we're diving into the good stuff. Motion control for Beavertronics means optical encoders, magnetic encoders, gyroscopes, accelerometers, and pulse width decoders.

There are two types of encoders:

- Absolute encoder
- Incremental encoder

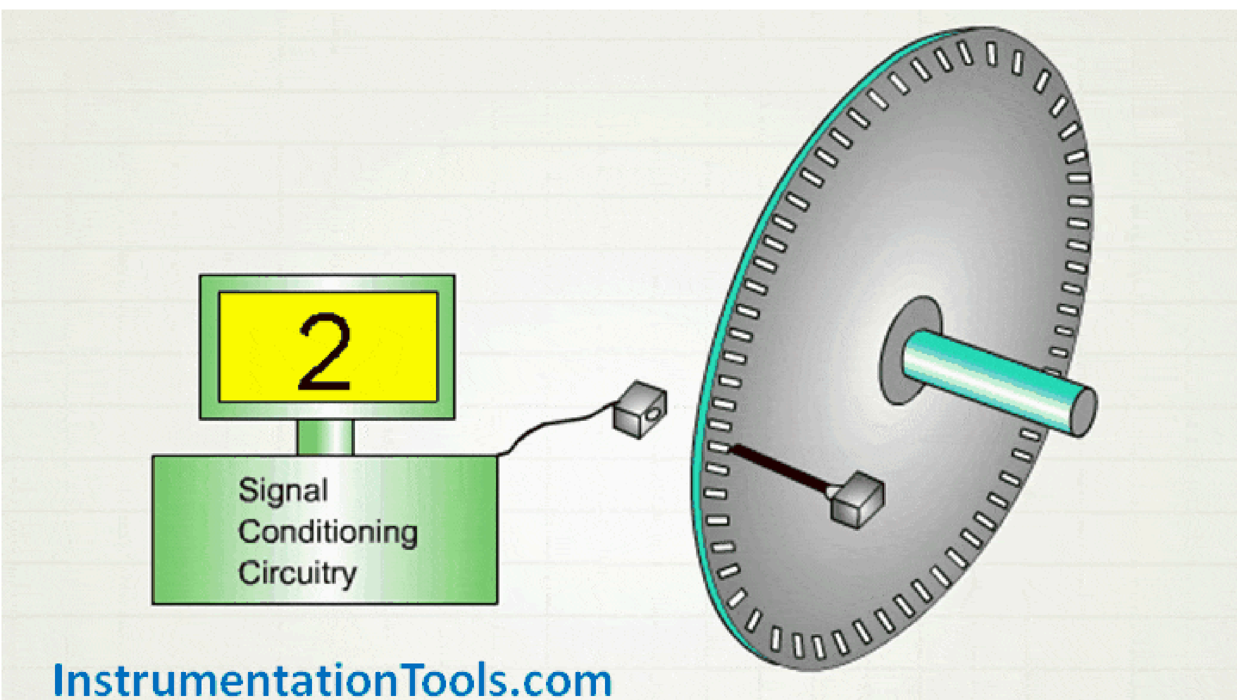
Absolute encoders output unique bits of information for each rotational position of the rotating device. These encoders may be found useful in lever arm mechanisms (e.g. 2910 Jack in the Bot's 2019 arm) that require positional control.

Incremental encoders are more useful for speed control, but can be used for position if boolean sensors are used to initialize the position of the encoder. Incremental encoders are often seen on drivetrains for autonomous control, and can also be used to control constant current mechanisms, such as flywheel shooters.

Rotary Encoders: Optical

The picture above is the optical grayhill encoder that you've probably seen chilling out on the drive train gearboxes. In an ideal world, the programmers would actually implement programs to put to use the encoders we've provided them.

These encoders work by use of LEDs. A single beam of light is shone at a slotted disc, so that a light sensor on the other side of the disc senses pulses -- hence, the pulses per second of this incremental encoder.



Testing & Troubleshooting

The wiring of the control system is the most fun to learn and develop, however, a large part of the job for electrical subteam workers ends up being testing and troubleshooting. Thus, it is critical that you electrical minions are properly trained in diagnosing, assessing, and confronting an electrical hiccup.

When something is not working, the first question should always be: is it plugged in? Check that first. I cannot stress this enough. Check that it is actually, positively, absolutely plugged in. (Or else programmers will come and personally yell at you -- graciously and professionally, of course.) That being said, DO advocate for yourself during the initial design stages and ensure that electrical access is a priority; remind those high-and-mighty mechanical and design leads that without electrical and programming, their robot is dead -- that starts with making sure all wires are plugged in properly.

Okay, so all the connections seem to be in place, but it's still not working. The code has been simulated and the problem does not seem to be there (despite all attempts to blame programming). Now, what? Look for a short-circuit.

How to Use a Multimeter

Use this video to familiarize yourself with the multimeter.

In order to test for a short-circuit to the frame, complete the following procedure:

1. Connect the black banana plug to the COM terminal and the red banana plug to the Resistance terminal.
2. Unplug the Anderson connector from the PDP to the 12V battery.
3. Set your digital multimeter to measure resistance (in Ohms).
4. Touch the black COM probe to the 6AWG PDP GND wire by sticking the probe inside the Anderson connector.
5. Touch the red probe to the frame.
6. There must be a reading of >3k Ohms or else you've got yourself a problem (preferably infinite resistance). In this case where you have a problem, closely study each wire connection, performing tug tests. After fixing these connections, run through this procedure again. If your problem is still not resolved, check any connections secured by electrical tape, as this tends to be faultier than heat shrink.

Shorts that do not touch the frame are harder to diagnose. They can happen for a variety of reasons, and it is always much easier to avoid these risk factors all together instead of working backwards:

- Metal shavings in the electrical
- Exposed wire (stripped too much OR frayed)
- Inadequate connection (e.g. not pushed in far enough)
- Water. (Yes, indeed, water gamers. You know who you are.)
- Damaged wire insulation

To read more about how to avoid short-circuits, visit Wire Organization: Fasteners, Secure Connections, Traceable Wiring.

RoboRIO

Wire Organization: Fasteners, Secure Connections, Traceable Wiring

This is the drag part of electrical. Kind of.

It seems like it is. But in reality, learning about various types of connectors is my idea of a fun Saturday afternoon, especially when that connector can mean life or death (of the robot, mid-match). In summation, this will seem boring to new electrical members, but to veteran electrical subteam members, roll up your sleeves, we are about to party!

Also included in this section is how to organize wire effectively in order to avoid situations where arm mechanism sprockets chomp encoder wires in half.

Soldering & Tinning

When people think of an electrical subteam, they usually picture a gaggle of teens hunched around soldering irons, hopefully in a well ventilated area. For those of you who don't know, soldering (pronounced sod-der-ing in America) is a technique used to establish electrical connections. Solder itself is a metal alloy with a melting point range of around 90 to 450 degrees celsius. In order to solder, you'll need to follow these few steps:

1. Gather materials (* means required)
   - ❏ Soldering iron*
   - ❏ Tip-cleaner* (either moist sponge or copper coils)
   - ❏ Solder spool*
   - ❏ Alligator clips* (to hold the objects being soldered)
   - ❏ Solder wick
   - ❏ Microscope or magnifying glass
2. Set up your station in a well ventilated area. This is most important when your solder contains lead. For our purposes, always look for lead-free solder since it's significantly safer to handle.
3. Determine the type of soldering task you will be completing:
   - ❏ Wire tinning
   - ❏ Precision soldering
   - ❏ Wire extensions

Here are some extra resources to access for perfecting your soldering skills:

Through-hole (THT) & Surface-mount (SMD)

Additional Resources

Comprehensive Guides:

Wiring the 2019 FRC Control System (WPI)

Team 358 Control System 2015

Team Appreciate 2468 Wiring your Robot

Robot Wiring Citrus Circuits 1678

FTC Skystone Wiring Guide

Team 4994 Electrical Bible

First Robotics Documentation

RoboRIO and Sensors Guides:

NI roboRIO User Guide

Citrus Circuits 1678 RoboRIO and Sensors Guide

LigerBots 2877 Vision Processing

Alternative Options:

Rotary Limit Switch