4. CONTROL SYSTEM MANUAL

4.1 Introduction & General Description

(see controls rules in section 3.3)

Please read the following section carefully. Failure to configure your control system properly could result in personal injury, damage to the control system, or damage to your robot. FIRST will not provide free replacement of control system parts damaged due to misuse or mis-wiring.

In this section you will find:

- Descriptions of the control system components
- Configuration options
- Wiring diagrams
- Hook-up instructions
- Rules for usage

If, after reading this section, you have problems configuring the control system, please contact FIRST for assistance. We will be happy to answer any questions you may have. See section 5.1 for information on how to contact FIRST.

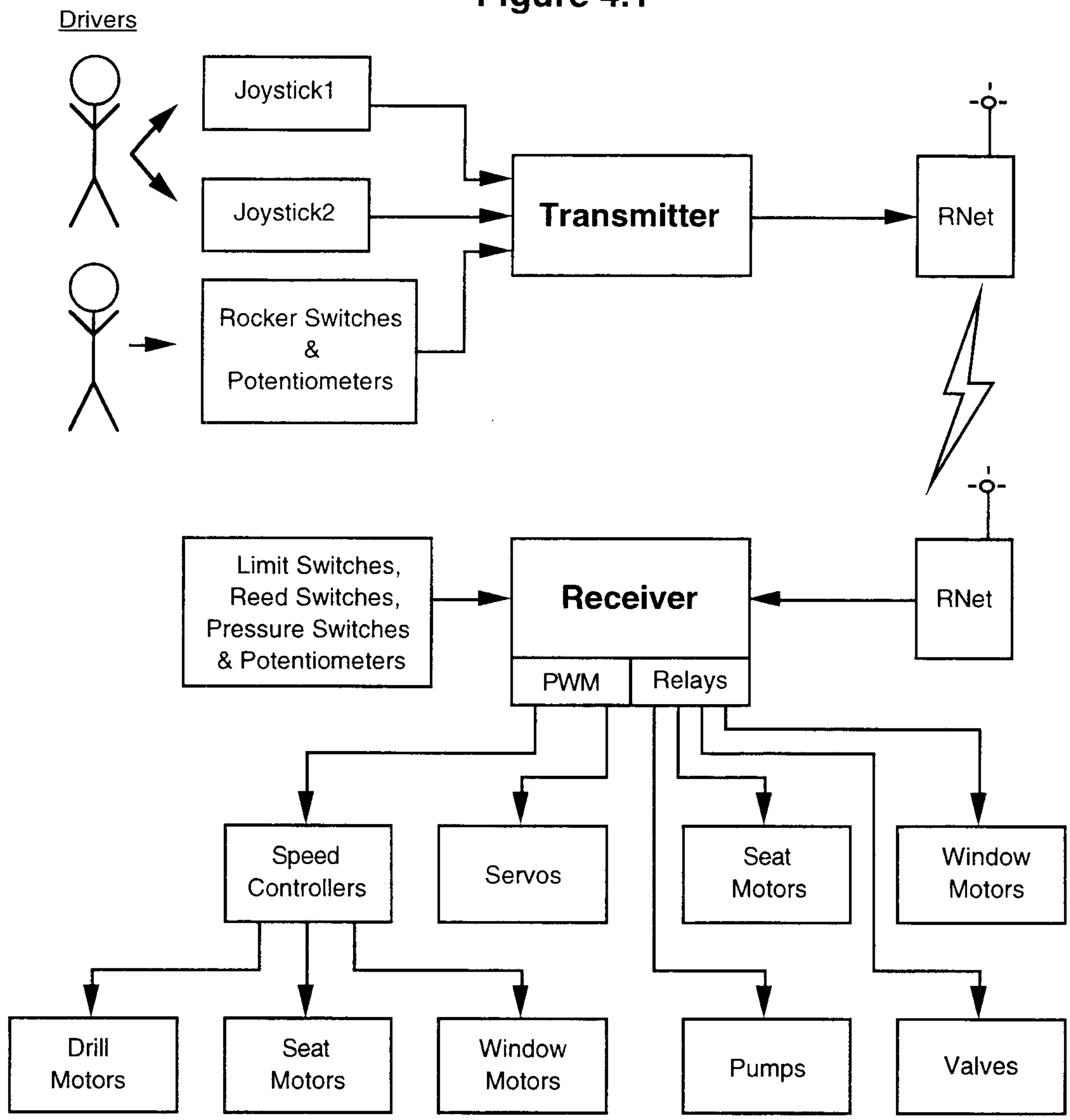
Before proceeding with a discussion of the individual components that make up the control system, it is helpful to understand the overall function of the control system.

The heart of the control system is comprised of two main units: the Transmitter, and the Receiver. Basically, the Transmitter takes input from the drivers and passes it along to the Receiver. The Receiver takes this information, gathers more information from sensors on-board the robot, figures out what to make the robot do, and makes the robot do it.

More specifically, the Transmitter reads the joystick, switch, and potentiometer inputs controlled by the drivers and relays this information to the Receiver via the RNet radio modems (or tether cable). The Receiver takes this information, verifies that it has been received correctly, and then hands it off to the user program. The user program, which runs on the receiver, takes the data from the Transmitter, reads the on-board sensor inputs, figures out what to do with the outputs to make the robot behave as desired, and sets the PWM and relay outputs to the appropriate states. Figure 4.1 shows a block diagram illustrating this concept.

The rest of this section will provide the details necessary to hook up the control system and make it work.

Control System Block Diagram
Figure 4.1



4.2 Control System Components

The Kit contains a variety of input devices:

- Two CH Products three-axis proportional joysticks with trigger and thumb switches
- Eight Honeywell Microswitch rocker switches
- Ten Honeywell Microswitch limit switches
- Four CP Clare reed switches.
- Two Numatics pressure switches
- Four potentiometers

The rocker switches are meant for use with the Transmitter to provide up to 16 switch inputs. In addition, there are two switch inputs on each joystick, which share input channels with 4 of the rocker switch inputs. If desired, the joystick switches can be disabled by setting some DIP switches inside the Transmitter.

Both joysticks and 2 of the potentiometers can be used with the Transmitter to provide up to 8 channels of proportional input.

The limit switches, reed switches, and pressure switches are intended for use as feedback sensors on your robots, but may also be used as part of the user interface on the Transmitter end. The Receiver can handle up to 16 switch inputs, so all of these switches can be used on the robot at once.

The remaining 2 potentiometers can be used with the Receiver to provide 2 channels of proportional input on-board the robot.

There are also a variety of output devices:

- Two Hitec servos
- Four Tekin reversing speed controllers
- Two Skil cordless drill motors
- Four Delco seat motors
- Two Delphi tape drive window mechanisms
- Two McCord-Winn Textron air pumps
- Two Numatics pneumatic valves.

The servos provide proportional position control, while the speed controllers provide proportional velocity control. Both the servos and speed controllers are controlled directly by the PWM outputs on the Receiver.

Due to their high current requirements, the drill motors may be driven only by the speed controllers. Also, no more than one motor may be powered by each speed controller. If proportional control of the seat or window motors is desired, they may also be driven by speed controllers.

Attempting to drive the drill motors directly with the Receiver relay outputs could damage the control system and is therefore prohibited.

All other output devices must be driven by the relay outputs on the Receiver. No more than one device may be powered by a single relay output.

4.3 Power Distribution

The Transmitter is powered by the 9Vdc power supply. In turn, the transmitting RNet receives power from the Transmitter.

On the Robot, power distribution is more complex. Power is provided by a pair of Skil rechargeable Ni-Cad batteries directly to the Receiver, speed controllers, and the muffin fan. All other devices receive power through the Receiver.

The batteries must be wired in parallel, such that the final output voltage is still 12Vdc, but the current capacity is doubled.

> **Do not wire the batteries in series. This will yield 24Vdc, and many components of the control system will be damaged.**
>
> **Important: The Skil batteries are designed to be able to sustain an output current of 70 Amps each, but will blow an internal safety fuse in less than 3 seconds at 100 Amps. If this fuse blows, the battery is dead and cannot be repaired. When under heavy load, such as with both drill motors stalled, a robot can draw more than 100 Amps, which is enough to kill a single battery. Therefore, robots must only be operated with both batteries present and wired in parallel, which will halve the load on each battery. FIRST will not provide free replacement of batteries with blown fuses.**

To provide a measure of protection, one 30A auto-resetting circuit breaker (provided in the Kit) must be installed in series with the positive terminal on each battery contact (one breaker/battery), such that all battery output flows through this breaker. These circuit breakers must be accessible for inspection at each Competition event.

Although not required, it is recommended that power from the batteries be distributed via the terminal strips, with one strip used for +12Vdc distribution, and the other strip used for GND. Also, if desired, the terminal strips may be rearranged into units with more or less channels and used to distribute power in multiple locations on the robot. This is not recommended, however, because each channel is designed to hold only one wire in each end.

With time, wires in terminal strips can become loose as the soft copper wire strands creep under the pressure of the screw. Also, normal operating vibration of a robot can loosen wires. Be sure to check the wires in the terminal strip on a periodic basis to prevent failures which could harm the control system or cause a robot to stop dead in the middle of a match.

In order to minimize mistakes and facilitate diagnosis of any problems, all wires distributing power with a constant polarity (i.e. not a relay or speed controller output) must be color coded as follows:

- Use Red 12 AWG or White 16 AWG wire for +12Vdc.
- Use Black 12 AWG or Black 16 AWG wire for GND.

The wires and cables included in the kits are intended for specific uses. Table 4.1 shows the minimum wire sizes allowed for hookup of the various control system devices.

Table 4.1: Minimum Wire Size by Device Type

Device	Wire Type
drill motors, speed controllers (power & motor leads), Receiver (power input)	12 AWG, red & black
Receiver (relay outputs), seat motors, window motors, pumps, valves, fan	16 AWG, 2 conductor
limit switches, reed switches, pressure switches, PWM cables, rocker switches	22 or 24 AWG, 2 or 3 conductor

Figure 4.2 shows a schematic for power distribution using the terminal strips.

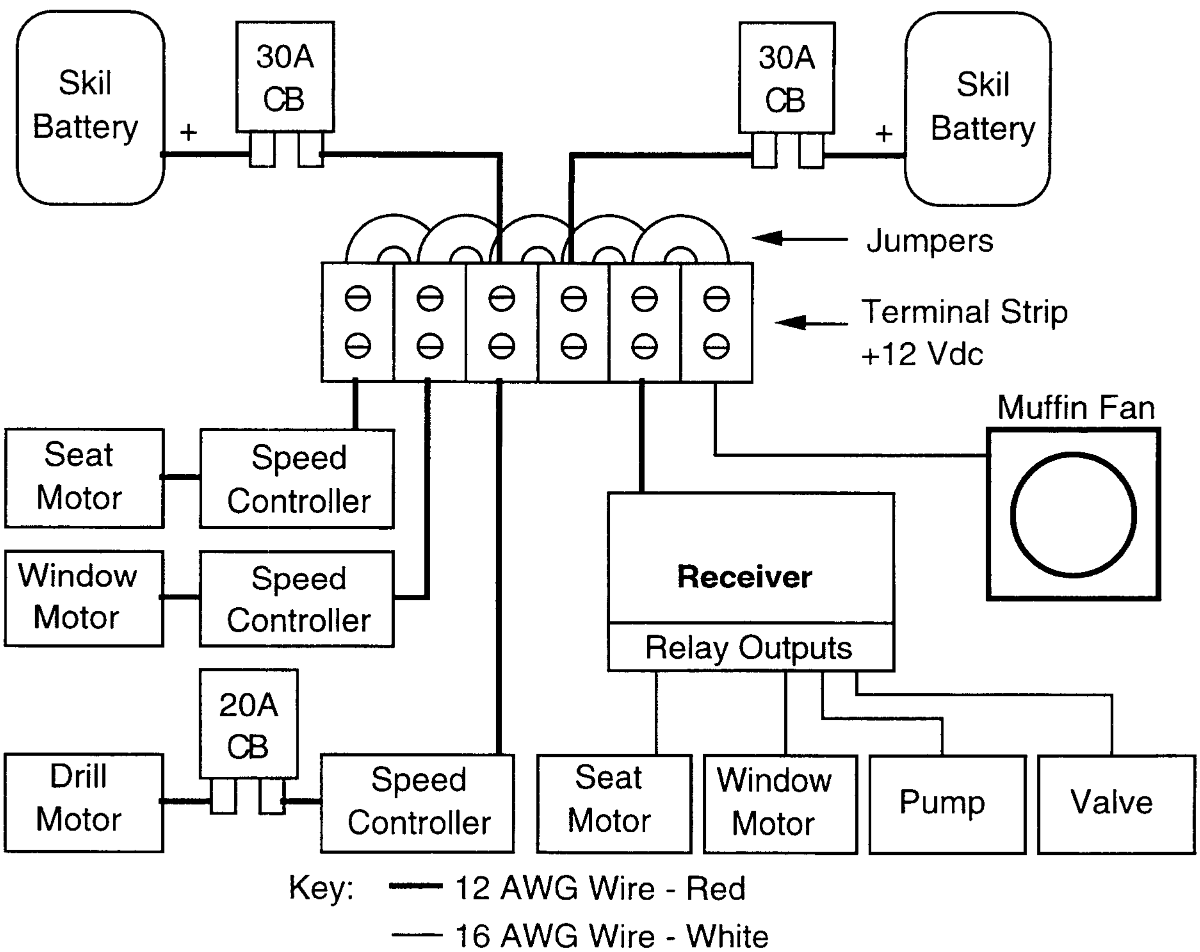


Figure 4.2 Power distribution

Note that Figure 4.2 shows only the +12Vdc side of the power distribution. The GND side is identical except for the absence of the circuit breakers.

The control system cables containing 3 wires or less may be shortened or lengthened as needed as long as the following conditions are met:

- Proper insulation (electrical tape, wire nuts, or shrink wrap) must be used.
- Proper wire type, as specified above, must be used.

4.4 Transmitter

The Transmitter reads the joystick, switch, and potentiometer inputs controlled by the drivers. It relays this information to the Receiver via the RNet radio modems (or tether cable). This allows the drivers to tell the robot what to do, such as turn left or extend an arm.

The connection diagram for the Transmitter Box is shown in Figure 4.3.

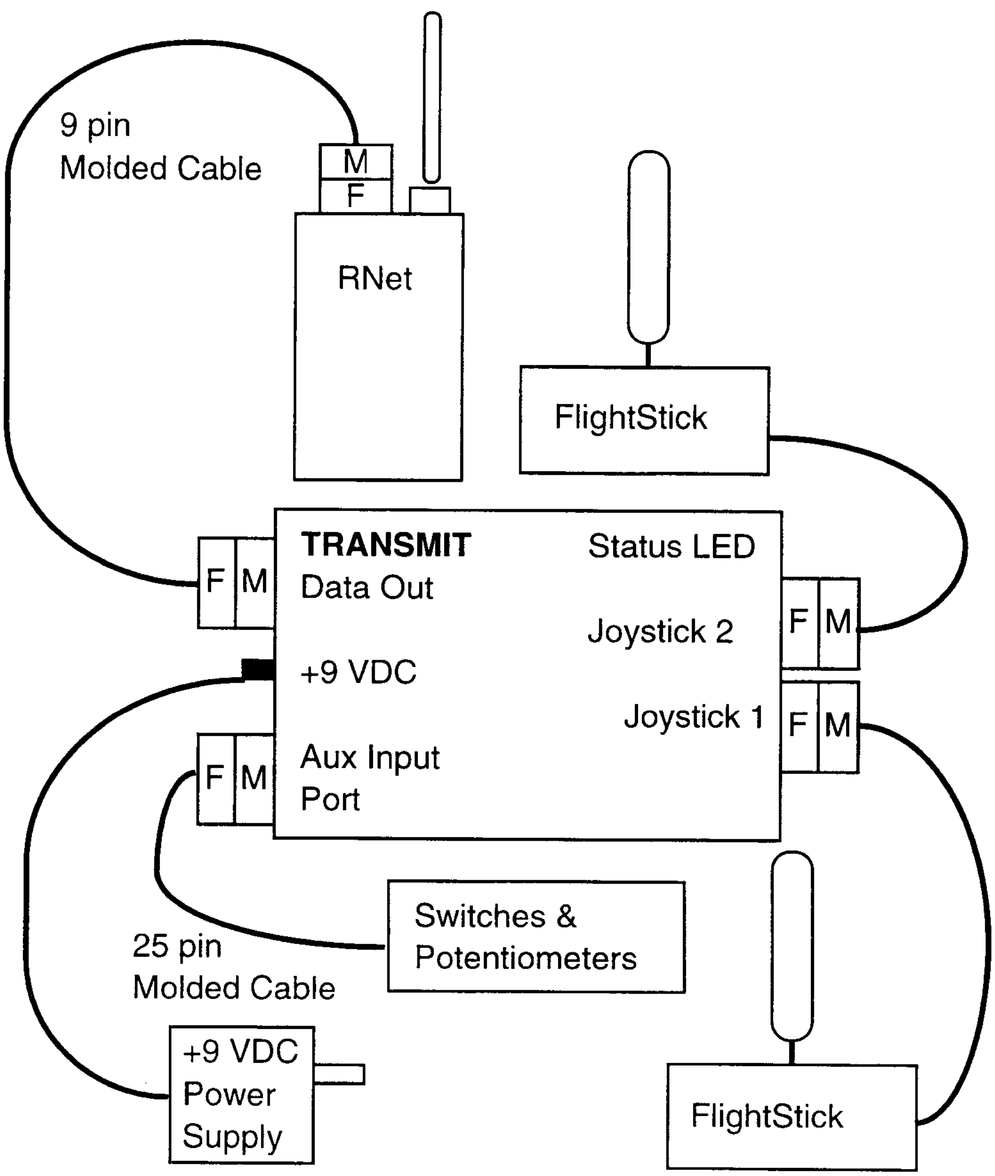


Figure 4.3 - Connection Diagram for Transmitter Box

<u>Warning</u>

Only the 9 volt power supply included with the Kit should be used to power the Transmitter box. If you experience any problems with the 9 volt power supply, contact FIRST for a replacement. Use of an alternate power supply could damage the Transmitter box or RNet and is therefore prohibited.

In order to connect the rocker switches and potentiometers to the Transmitter, they must be wired to the 25 pin male connector and mounted inside the black/almond project box. The 25 pin cable must then be used to make the connection from the 25 pin connector in the project box to the auxiliary input port on the Transmitter.

The exact wiring configuration for the switches and potentiometers inside the project box is not specified. Instead, teams may wire these devices as desired to work with the software and output devices connected to the Receiver. Table 4.2 shows the pin assignments for the auxiliary input port.

Table 4.2: Auxiliary Input Port Pin Assignments with Corresponding Control Program Variable Names

Pin Description	RX Variable	Pin Description	RX Variable
Pin 1: +5Vdc	-	Pin 14: +5Vdc	-
Pin 2: Switch Input 6	sw3_rev	Pin 15: Switch Input 5	sw3_fwd
Pin 3: Switch Input 2 (top button - Joystick 1)	sw1_rev	Pin 16: Switch Input 1 (trigger button - Joystick 1)	sw1_fwd
Pin 4: Analog Input 2	aux1	Pin 17: Switch Input 8	sw4_rev
Pin 5: Switch Input 7	sw4_fwd	Pin 18: Switch Input 4 (top button - Joystick 2)	sw2_rev
Pin 6: Switch Input 3 (trigger button - Joystick 2)	sw2_fwd	Pin 19: Analog Input 2	aux2
Pin 7: Ground	-	Pin 20: Ground	-
Pin 8: Ground	-	Pin 21: Switch Input 16	sw8_rev
Pin 9: Switch Input 15	sw8_fwd	Pin 22: Switch Input 14	sw7_rev
Pin 10: Switch Input 13	sw7_fwd	Pin 23: Switch Input 12	sw6_rev
Pin 11: Switch Input 11	sw6_fwd	Pin 24: Switch Input 10	sw5_rev
Pin 12: Switch Input 9	sw5_fwd	Pin 25: +5Vdc	-
Pin 13: +5Vdc	-		

Switch inputs should be closed to Ground or left open to achieve a 1 or 0 state, respectively, on the Receiver.

Do not connect switches to +5Vdc.

<u>The analog input ports on the Transmitter read resistance, not voltage</u>. To connect a potentiometer to the auxiliary input port, connect one of the outer

potentiometer connectors to +5Vdc and the middle connector (wiper) to the analog input pin of your choice.

Do not connect a potentiometer between +5Vdc and Ground on the Transmitter.

The switch inputs on the joysticks are wired in parallel with some of the switch inputs on the auxiliary input port, as indicated in Table 4.2. If desired, the switch inputs on the joysticks can be selectively disabled by changing the settings of DIP switches inside the Transmitter. To change the DIP switches, the Transmitter must be opened by removing the four screws on the bottom cover. Table 4.3 details the Transmitter DIP switch settings.

Attention: Before opening the Transmitter box, remember to disconnect the power supply. While the Transmitter box is open, be careful to avoid static discharges to the circuit board or connectors. Also, make sure not to let any foreign particles, especially metal fragments, get inside the enclosure or onto the circuit board. It is best to open the unit in a clean environment away from where your robot is being worked on. Never operate the Transmitter with the cover off.

Table 4.3: Transmitter DIP Switch Settings

Button	DIP Switch
Joystick 1 - Top	3
Joystick 1 - Trigger	4
Joystick 2 - Top	7
Joystick 2 - Trigger	8

Figure 4.4 shows the location of the DIP switches on inside the Transmitter box. To access the DIP switches, the cover of the Transmitter box must be removed. To remove the cover, unscrew the four Phillips head screws on the underside of the Transmitter box.

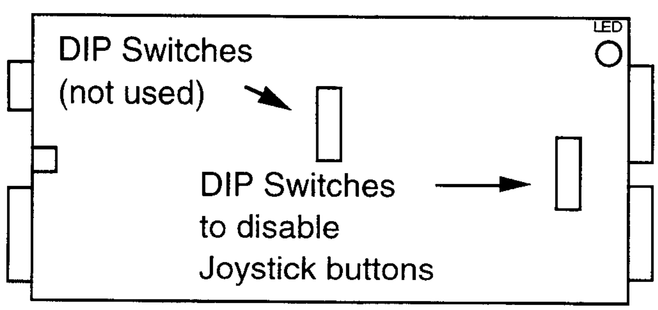


Figure 4.4: Location of DIP Switches Inside Transmitter Box

4.5 Receiver

The Receiver takes data from the Transmitter, verifies that it has been received correctly, and then hands it off to the control program. The default control program takes the data from the Transmitter, reads the on-board sensor inputs, and sets the PWM and relay outputs to the appropriate states. Table 4.4 shows the mapping of Transmitter and Receiver inputs to Receiver outputs when the default program is running.

Table 4.4 - Input to Output Mapping of Default Receiver Program

Input	Output
Joystick 1 - X Axis	PWM1
Joystick 1 - Y Axis	PWM2
Joystick 2 - X Axis	PWM3
Joystick 2 - Y Axis	PWM4
Auxiliary Input Port - Analog #1	PWM5
Joystick 1 - Thumbwheel	PWM6
Auxiliary Input Port - Analog #2	PWM7
Joystick 2 - Thumbwheel	PWM8
TX Switch 1, (RX Switch 1 turns off)	Relay Output 1 (F)
TX Switch 2, (RX Switch 2 turns off)	Relay Output 1 (R)
TX Switch 3, (RX Switch 3 turns off)	Relay Output 2 (F)
TX Switch 4, (RX Switch 4 turns off)	Relay Output 2 (R)
TX Switch 5, (RX Switch 5 turns off)	Relay Output 3 (F)
TX Switch 6, (RX Switch 6 turns off)	Relay Output 3 (R)
TX Switch 7, (RX Switch 7 turns off)	Relay Output 4 (F)
TX Switch 8, (RX Switch 8 turns off)	Relay Output 4 (R)
TX Switch 9 or RX Switch 9	Relay Output 5 (F)
TX Switch 10 or RX Switch 10	Relay Output 5 (R)
TX Switch 11 or RX Switch 11	Relay Output 6 (F)
TX Switch 12 or RX Switch 12	Relay Output 6 (R)
TX Switch 13 or RX Switch 13	Relay Output 7 (F)
TX Switch 14 or RX Switch 14	Relay Output 7 (R)
TX Switch 15 or RX Switch 15	Relay Output 8 (F)
TX Switch 16 or RX Switch 16	Relay Output 8 (R)
RX Analog Input 1	Not Used
RX Analog Input 2	Not Used

If desired, a custom user control program can be loaded into the Receiver to provide more sophisticated control of the robot. Adding a user control program will not erase the default control program, so the Receiver can be changed back to use the default program quickly and easily in the event of problems with the custom program. DIP switches on the side of the Receiver are used to select which program (default or custom) is running, and to reset the Receiver in the event of a problem. Table 4.5 shows the Receiver DIP switch settings.

Table 4.5: Receiver DIP Switch Settings

DIP Switch	Setting
1	Default control program
2	User control program
3	Reset
4	Not Used
Notes: To select an option, place the appropriate switch in the down position. Only one program (default or user) can run on the Receiver at once. If neither or both programs are selected, the Receiver will not function properly. In order to load a user control program into the Receiver, the DIP switches must be set for the user control program. The Receiver is designed to prevent the default control program from being overwritten.	

Programming the Receiver

The control program running on the Receiver is written PBASIC, a dialect of the BASIC programming language. This language was selected because it is fairly easy to learn and debug in a short period of time. However, as with all programming languages, it is possible to create a program that does not behave as expected. If a custom control program is used, the team assumes full responsibility for insuring that the code works as expected.

> **It must be clearly understood that teams are responsible for any software bugs introduced into the control program when using a custom program. If a software bug negatively impacts the performance of a robot during a competition match, it will not be grounds for a rematch or even a pause in the match.**

To program the Receiver, use the software included on the disk labeled "Programming Software for Control System". This disk contains a copy of the program editor/compiler/programming utility (STAMP2.EXE), the source code for the default control program (RXSLAVE.BS2), and complete documentation for the STAMP2 program and the PBASIC programming language (BS2BOOK.PDF & BS2APPS.PDF). With the exception of the source code for the default control program, these files can also be obtained via the Internet from Parallax, Inc. at http://www.parallaxinc.com or ftp://ftp.parallaxinc.com.

The documentation files are in Adobe's Portable Document Format (PDF). Programs to view these files are available over the Internet for free for most operating systems from Adobe at http://www.adobe.com.

The source code for the default control program is provided both as an example of how to write a program in PBASIC, and to provide a head start in writing a custom program. It is recommended that the RXSLAVE.BS2 file be copied, and that the copy be used to write any custom control software. This way, the original file will always be available as a backup. The source code for the default control program is also available in Appendix J.

In order to program the Receiver, the 9pin cable must be connected from the serial port of a PC to the Programming Port on the Receiver.

RNets and Tether Adapter

The Receiver gets data from the Transmitter either via the RNet radio modems or a direct connection via the tether adapter. The 2 ends of the 3-headed cable are used to connect the multi-frequency RNet to the Data In Port on the Receiver. The other end of this cable should be mounted in a position that is easy to access.

To operate the robot via wireless control, attach the dongle to the third end of the 3-headed cable. This will select the appropriate frequency and route data from the RNet to the Receiver.

To operate the robot with the tether adapter, remove the dongle, and connect the tether adapter to the third end of the 3-headed cable. Then, unplug the fixed-frequency RNet from the 9pin cable on the Transmitter, and plug this cable directly into the tether adapter.

Avoid bundling the 3-headed cable with the battery or motor wires. Locate the RNet so the antenna is not shielded by metal objects. The hook and loop fastener on the RNet provides an easy means of attachment to the robot. However, we recommend a secondary means of attachment because the RNets have broken loose in the past due to the serious impacts and vibrations the robots undergo during The Competition.

PWM Outputs

The PWM outputs are designed to drive the servos, and to provide a control signal to the speed controllers. The speed controllers and servos may be directly connected to the PWM outputs, or may be connected via the 36" servo extension cables and/or 24" servo Y cables. When plugging a PWM cable onto the output connectors, be sure to observe the orientation indicated on the label.

Some of the PWM cables in the kits have Hitec/JR style connectors while others have Futaba J-style connectors. The Hitec/JR style cables have yellow, red, and black wires, while the Futaba style cables have white, red, and black wires. These cables should be treated as equivalent. In order to use the Futaba style connectors, you may need to shave off the external tab to obtain a proper fit. See the figure 4.5 below for details.

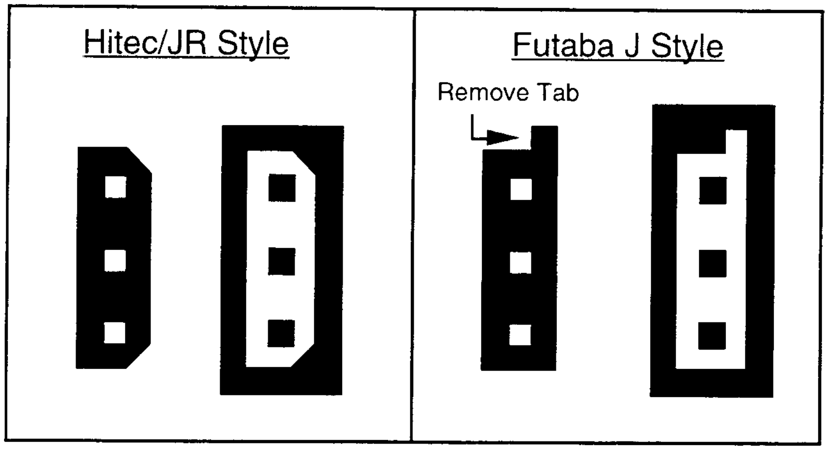


Figure 4.5: Hitec and Futaba-Style PWM Connectors

Relay Outputs

The relay outputs are designed to provide forward and reverse control of the seat motors, window motors, pumps, and valves. These outputs should be connected directly to the motor/pump/valve with the appropriate wire.

> **Do not run power from the batteries into the relay outputs. Doing so will damage the control system.**

To achieve control of both solenoids on the double solenoid valve and use only one relay channel, use the diodes provided in the kit to route power to one solenoid at a time. Figure 4.6 shows the schematic for this arrangement.

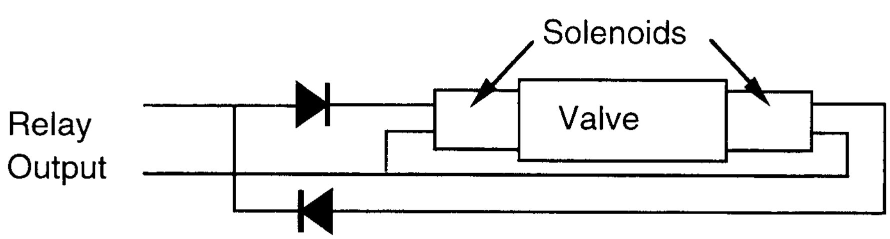


Figure 4.6: Use of Diodes with Double Solenoid Valve

Sensor Inputs

The sensor inputs on the Receiver can be used to measure various conditions on the robot and trigger automatic responses by the control software. For example, by mounting a limit switch in such a position that it is triggered when a mechanism reaches one of the ends of travel, the limit switch can be used to disable the motor from trying to travel further in that direction without preventing it from moving back in the other direction. This can prevent binding or damage to the mechanism, and can save energy by preventing the motor from operating in a stall condition.

There are 16 switch inputs and 2 analog inputs available. The limit switches, reed switches, and air pressure switches may be connected to the switch inputs. The potentiometers may be connected to the analog inputs. Use 2 or 3 conductor jacketed cable and a 25 pin male soldercup connector to connect sensors to the Sensor Port. Table 4.6 describes the pin assignments for the Sensor Port.

Do not connect power or any other signals to these switches or switch inputs. Be careful to observe the polarity of the power inputs when wiring the control system. You will be required to pay for replacement or repair of devices damaged due to improper wiring.

Table 4.6: Sensor Port Pin Assignments with Corresponding Control Program Variable Names

Pin Description	RX Variable
Pin 1: Switch Input 1	rx_sw1
Pin 2: Switch Input 2	rx_sw2
Pin 3: Switch Input 3	rx_sw3
Pin 4: Switch Input 4	rx_sw4
Pin 5: Switch Input 5	rx_sw5
Pin 6: Switch Input 6	rx_sw6
Pin 7: Switch Input 7	rx_sw7
Pin 8: Switch Input 8	rx_sw8
Pin 9: Ground	-
Pin 10: Ground	-
Pin 11: Ground	-
Pin 12: Ground	-
Pin 13: +5Vdc	-
Pin 14: Switch Input 9	rx_sw9
Pin 15: Switch Input 10	rx_sw10
Pin 16: Switch Input 11	rx_sw11
Pin 17: Switch Input 12	rx_sw12
Pin 18: Switch Input 13	rx_sw13
Pin 19: Switch Input 14	rx_sw14
Pin 20: Switch Input 15	rx_sw15
Pin 21: Switch Input 16	rx_sw16
Pin 22: Ground	-
Pin 23: Ground	-
Pin 24: Analog Input 1	sensor1
Pin 25: Analog Input 2	sensor2

Switch inputs should be closed to Ground or left open to achieve a 1 or 0 state, respectively.

Do not connect switches to +5Vdc.

The analog input ports on the Receiver read a voltage between 0 to +5Vdc. To connect a potentiometer to the auxiliary input port, connect one of the outer potentiometer connectors to +5Vdc, the other outer connector to Ground, and the middle connector (wiper) to the analog input pin of your choice.

Do not connect any voltages greater than +5Vdc to the analog input port. It will damage the Receiver.

4.6 Output Devices

Skil Gearmotors and Tekin Speed Controllers

Refer to the Tekin REBEL Owner's Manual for connection of the speed controller to the battery and motor. Two capacitors, included with each speed controller, should be installed on each drill motor as described in the Owner's Manual. Please secure the motor wires carefully to avoid breaking the capacitor leads.

One 20A circuit breaker must be installed in series with each drill motor to protect both the drill and the speed controller. Do not disable the circuit breaker by connecting its terminals together. Please insulate the terminals of this circuit breaker separately so inspectors at The Competition can verify correct installation. If the circuit breaker trips during use, you should use a higher gear reduction ratio. The circuit breaker usually resets in less than one second.

If the speed controller shuts off due to overheating during use, you may need to use a higher gear reduction ratio, or you may be running it continuously in reverse. The speed controller runs hotter in reverse than it does in forward. The speed controller usually takes 30 seconds or more to reset. An optional 12V muffin fan has been included in the Kit primarily for added protection against overheating of speed controllers and/or drill motors. You should install this fan to direct cooling air over the power components that run the hottest. You may provide power to the fan from the 12V power distribution terminal blocks directly. Note that the fan is not reversible.

The drill motors and gearboxes snap together for convenient handling during assembly of a drill; this motor-gearbox sub-assembly cannot support normal loads by itself. The gearshift lever on the gearbox and the gears actuated by it cannot withstand large gear-shifting forces, especially while operating. We recommend that you use the plastic drill shell to support the motor, gearbox and shift mechanism, and provide ample speed reduction between the drill and its load.

The drill components were designed for drilling holes and driving screws, not for propelling a 120 pound robot or launching huge tubes several feet into the air. Please remember this when designing and operating your robot. Align mechanical power transmission components accurately. If you couple the spindle to another shaft, support the shaft with two bearings and use a suitable flexible coupling. If you mount a gear, pulley, or sprocket to the gearbox spindle, use the largest pitch diameter possible to minimize side loads resulting from transmitting torque. Note the tradeoff between side loads and available gear ratio. A small pulley on the spindle allows a good gear ratio, but results in excessive side loads. Seriously consider the possible need for two stages of speed reduction between the drill and its load. If the drill shows signs of overloading, such as clutch disengagement, improve your design. When you get out on the playing field, failures will be far more likely than they were during practice.

Seat and Window Motors

The seat and window lift motors contain one worm gear reduction stage and a positive temperature coefficient (PTC) thermistor for overload protection. As the motor becomes warm from use, the resistance of the PTC device increases, thereby reducing the motor current and output torque. Operation at or near stall continuously will reduce the output torque to near zero until the motor has been allowed to cool. To prevent overheating, take care to couple the output shaft in a manner that does not impose large side loads, use an appropriate gear ratio, and minimize the internal friction of the mechanism driven.

Mechanical Power Transmission

One of the most common problems teams have experienced in past competitions is mechanical power transmission failure. Typical torques at the final stage of your propulsion power transmission assembly are large enough to cause serious problems for most conventional means of fixing gears, pulleys or sprockets to shafts. Set screws almost always fail. Pins offer better torque transmission, but can cost you valuable time if one breaks. Be careful not to use a pin so large that it occupies so much if the original shaft cross-section that the shaft breaks. Consider carefully the use of good clamping type couplings, even though they may be expensive. We have included two 3/8 in. bore Trantorque collet type couplings in the Kit, and recommend that you use them on the drill spindles. Although the Trantorque is intended for use on a smooth shaft, it has been used successfully on the threaded spindle. You should bore the component to be mounted a few thousandths of an inch smaller than the recommended 0.750 in. to compensate for the spindle diameter, which is slightly under 0.375 in. Be careful to avoid interference with other parts when installing the Trantorque coupling.

4.7 Batteries & Chargers

The battery chargers use a temperature sensor to terminate charging. A warm battery must be allowed to cool before the charger will begin charging. Please do not attempt to cool a battery by immersing it in ice, water, or snow. A battery that has been left out in cold weather must be allowed to reach room temperature before charging. Failure to do so will cause serious damage to the battery, which may leak toxic liquid as a result.

Be careful to avoid shorting the batteries. Short-circuit current exceeds 100A and can cause fire, serious injury, and leakage of toxic materials. If you have a battery that you know to be damaged, please do not put it in the trash. Turn it in to us and tell us that it is damaged, so we can recycle it properly.

Freshly charged batteries will be provided at The Competition for teams who have not had time to charge a pair fully for their next match. The best strategy when working in the pit is to trade one set of batteries at the FIRST charging station for a fresh set a few minutes prior to your next match and "top them off" with your own charger. Use the other set for testing in the pit.

Two batteries with an average load of 10A each will run for at least five minutes.

To plug batteries into the robot control system, use the handles of the drill shells in conjunction with the battery contacts. For convenience, the handles may be cut from the main body of the drill shell. It is recommended that the battery retaining clips also be used to provide an easy means of securing the batteries in the handles.

See Section 4.3 for information on acceptable wiring of the batteries.