4. CONTROL SYSTEM MANUAL

4.1 Introduction & General Description

(see controls rules in section 3.3)

WARNING

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 components damaged due to misuse or miswiring. Furthermore, teams will be required to correct control systems that are not configured according to this section and the control system rules in Appendix A before being allowed to compete.

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's Engineering Department 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 human drivers and passes it along to the Receiver. The Receiver takes this information, gathers additional information from sensors on-board the robot, determines how the robot should function, and has the robot perform the functions.

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 forwards it to the control program. The control program takes the data from the Transmitter, reads the sensor inputs on-board the robot, determines 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.

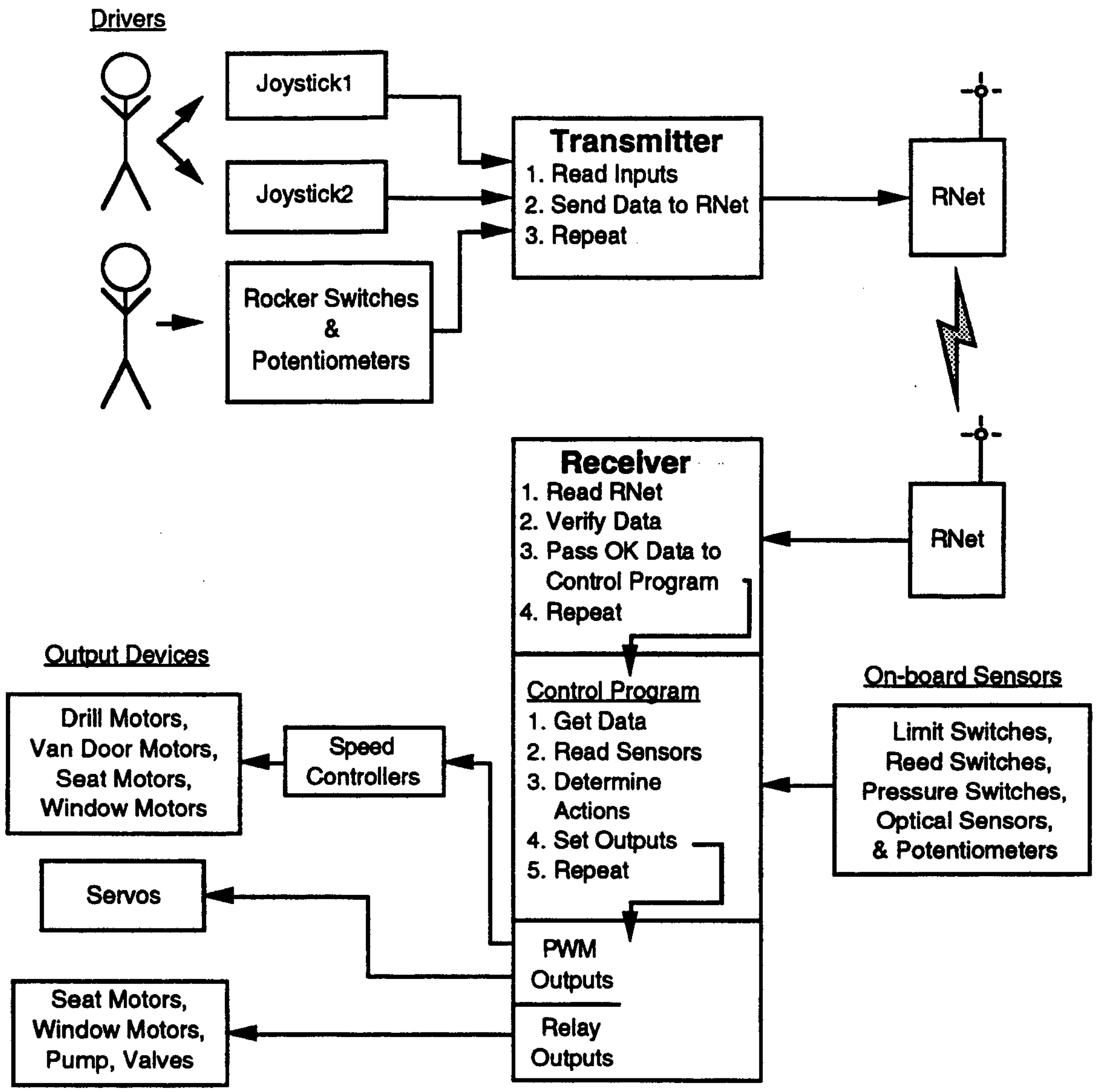

Figure 4.1: Control System Function Block Diagram

The rest of Section 4 provides the details necessary to hook up the control system and ensure that it operates properly.

4.2 Control System Components

The Kit contains a variety of input devices:

- Two three-axis proportional joysticks with trigger and thumb switches
- Eight rocker switches
- Ten limit switches
- Four reed switches
- Two pressure switches
- Four potentiometers
- Two optical sensors

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

The rocker switches may be used 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.

The limit switches, reed switches, and pressure switches are intended for use as feedback sensors on the robot, but may also be used for switch inputs on the Transmitter. The Receiver can handle up to 16 switch inputs.

The potentiometers may be used with the Receiver to provide up to 4 channels of proportional input on-board the robot.

Each optical sensor has two outputs which can be connected to the switch inputs on the Receiver.

There are also a variety of output devices:

- Two servos
- Four reversing speed controllers provided in the Kit of Parts
- Four additional reversing speed controllers which may be purchased
- Two cordless drill motors
- Two seat motors
- Two window motors
- One air pump
- Two pneumatic valves
- Two van door motors
- One light emmiting diode (LED)

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

Due to their high current requirements, the drill motors and van door motors may be driven only by the speed controllers. If proportional control of the seat or window motors is desired, they may also be driven by speed controllers.

Each speed controller may be used to power one drill motor or one van door motor or up to two total seat and/or window motors. No other combinations are allowed.

CAUTION

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

The LED is the only output device for use with the Transmitter. It may be powered by the +5 Vdc output on the Transmitter's Auxiliary Input Port.

All other output devices may be driven only 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 9 Vdc power supply. In turn, the transmitting RNet receives power from the Transmitter.

CAUTION

Use the 9 volt power supply included with the Kit to power the Transmitter. Use of an alternate power supply could damage the Transmitter and/or RNet and is therefore prohibited.

On the Robot, power distribution is more complex. Electrical power from a 12 Vdc sealed-lead-acid (SLA) battery is distributed, via a fuse, directly to the Receiver, speed controllers, muffin fan, and optical sensors. All other electrical devices may receive power only from the Receiver and/or speed controllers as described below.

WARNING

Be very careful to avoid short circuits! The 12 Vdc SLA battery can deliver current well in excess of 100 Amps for a sustained period of time (minutes). This level of power can make wires turn red hot and melt through the insulation in a fraction of a second, which can result in serious burns, scars, and/or other injuries. Short circuits can also destroy control system components and could cause the battery to leak highly corrosive acid or even explode. Always make sure the fuse is in series with the battery output. Please be careful!

For safety reasons, the battery fuse supplied in the kit must be wired in series with the +12 Vdc output terminal on the battery.

Although not required, it is recommended that power from the battery be distributed via the terminal strips, with one strip used for +12 Vdc distribution, and the other strip used for Ground. 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.

CAUTION

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. With time, wires in terminal strips can become loose as the soft copper wire strands creep under the pressure of the screw. Also, the normal operating vibration of a robot can loosen wires.

Figure 4.2 shows a schematic for +12 Vdc power distribution using the terminal strips.

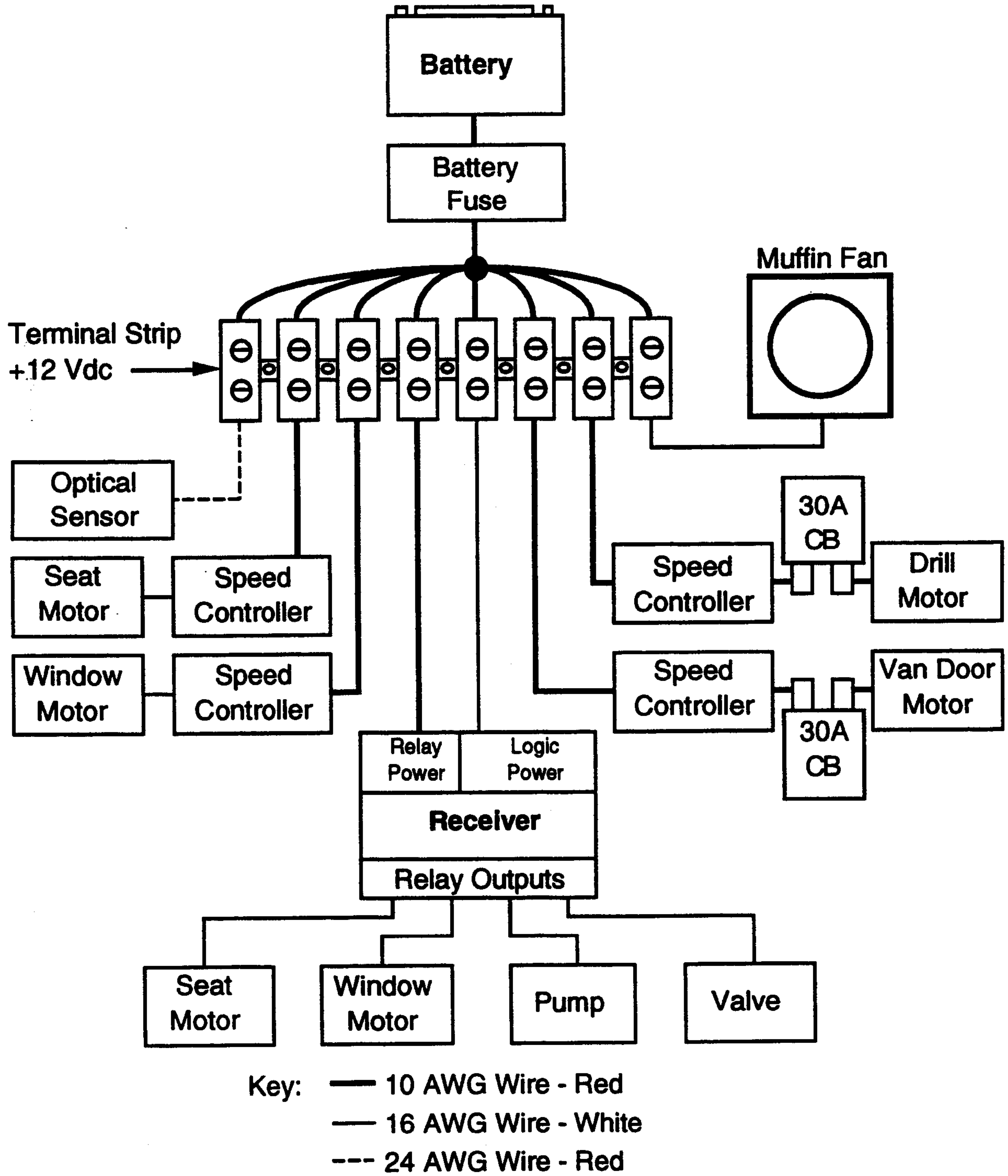

Figure 4.2: +12 Vdc power distribution

Note that Figure 4.2 shows only the +12 Vdc side of the power distribution. The Ground side is identical except for the absence of the circuit breakers, battery fuse, and optical sensors. The optical sensors are connected to Ground via the sensor port on the Receiver.

CAUTION

Do not connect the pump, valves, switches, or any motors directly to the battery. Do not connect battery power directly to the relay outputs as this may damage the Receiver.

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

- Use Red 10 AWG or White 16 AWG wire for +12 Vdc.
- Use Black 10 AWG or Black 16 AWG wire for Ground.

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, van door motors, speed controllers (power input, output to drill/van door motors), Receiver (relay power input)	10 AWG, red & black
Receiver (logic power, relay outputs), seat motors, window motors, speed controllers (output to seat/window motors), pump, valves, fan	16 AWG, 2 conductor
Limit switches, reed switches, pressure switches, PWM cables, rocker switches, potentiometers, optical sensors, LED	24 AWG, 2 or 3 conductor

Control system cables containing 4 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 heat shrink tubing) 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 is shown in Figure 4.3.

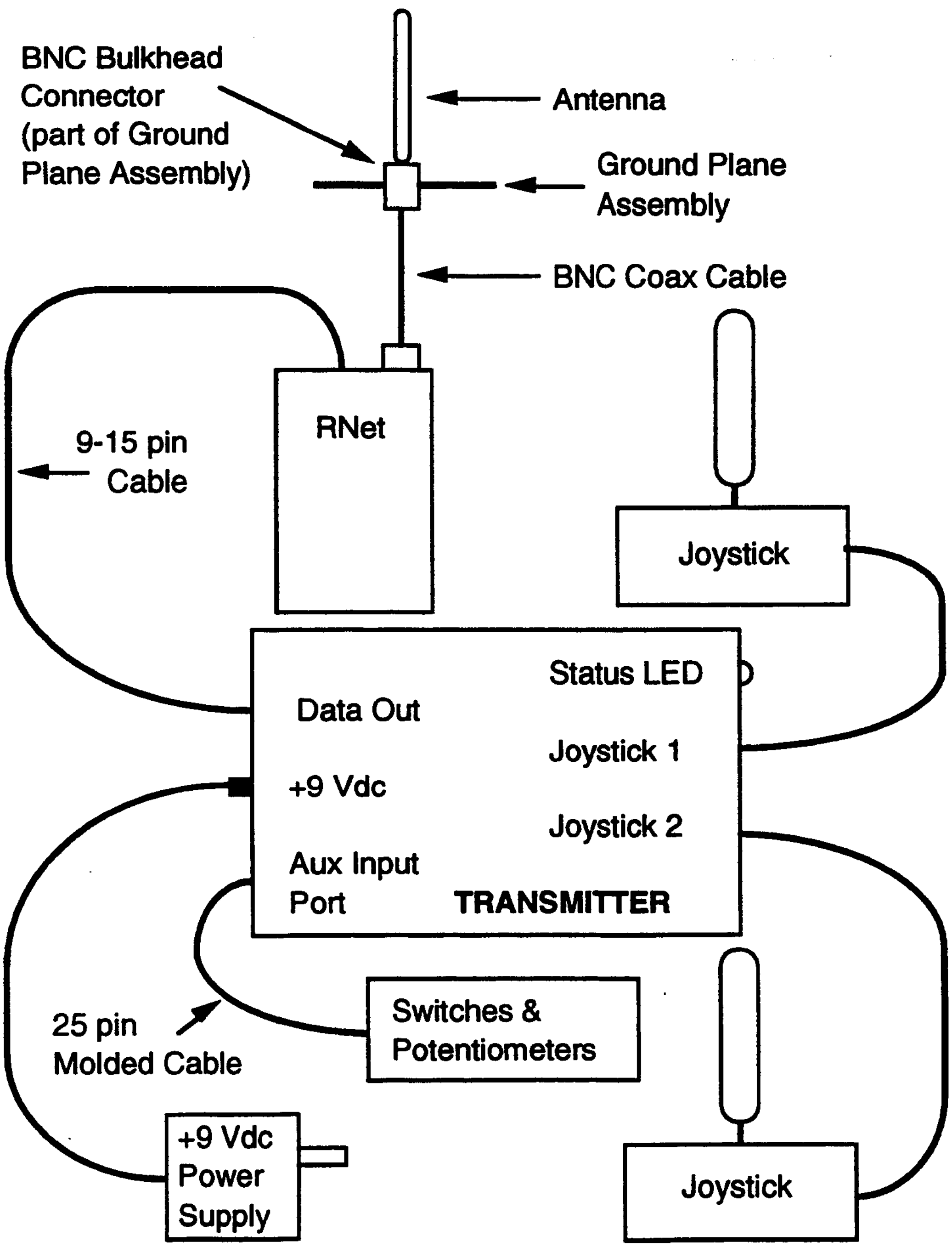

Figure 4.3: Connection Diagram for Transmitter

NOTES

There are also two types of Transmitters being used in the 1998 Competition. They are functionally identical, but the position of the connectors for Joystick 1 and Joystick 2 are reversed on some units.

To connect the Transmitter to the transmiting RNet, attach the 9 pin end of a 9-15 pin cable to the Data Out port on the Transmitter and the 15 pin end of the cable to the receiving RNet. Next, attach one end of a BNC coax cable to the BNC connector on the RNet, and the other end of the cable to the BNC bulkhead connector on the ground plane assembly. Finally, connect the antenna to the other side of the BNC bulkhead connector.

CAUTION

The antenna should not be connected directly to the transmitting RNet. Doing so will generate unwanted interference and may prevent the control system from working properly. Always use the BNC cable and ground plane assembly to separate the antenna from the transmitting Rnet.

For best reception of data, make sure that the ground plane is level with the floor and the antenna is pointing up.

In order to connect the rocker switches, potentiometers, and LED to the Transmitter, they must be wired to the 25 pin male soldercup connector. Although not a requirement, teams may use the black project box as a housing for the rocker switches, potentiometers, and 25 pin connector. The 25 pin molded cable must then be used to make the connection from the 25 pin connector to the auxiliary input port on the Transmitter.

The exact wiring configuration for the switches, potentiometers, and LED connected to the Transmitter is not specified. Teams may wire these devices, within the rules as described below, in order to create a custom interface for the drivers. Table 4.2 shows the pin assignments for the auxiliary input port.

Table 4.2: Transmitter Auxiliary Input Port Pin Assignments

Pin	Description	Pin	Description
1	+5Vdc	14	+5Vdc
2	Transmitter Switch Input 6	15	Transmitter Switch Input 5
3	Transmitter Switch Input 2 (shared with Joystick 1 top button)	16	Transmitter Switch Input 1 (shared with Joystick 1 trigger button)
4	Transmitter Potentiometer Input 1	17	Transmitter Switch Input 8
5	Transmitter Switch Input 7	18	Transmitter Switch Input 4 (shared with Joystick 2 top button)
6	Transmitter Switch Input 3 (shared with Joystick 2 trigger button)	19	Transmitter Potentiometer Input 2
7	Ground	20	Ground
8	Ground	21	Transmitter Switch Input 16
9	Transmitter Switch Input 15	22	Transmitter Switch Input 14
10	Transmitter Switch Input 13	23	Transmitter Switch Input 12
11	Transmitter Switch Input 11	24	Transmitter Switch Input 10
12	Transmitter Switch Input 9	25	+5Vdc
13	+5Vdc		

Switch inputs should be closed to Ground or left open to achieve a 1 (on) or 0 (off) state, respectively, in the data going to the Receiver. Further information about how the Transmitter inputs are used by the Receiver is included in Section 4.5.

NOTE

Do not connect switches to +5Vdc.

The potentiometer inputs on the Transmitter read resistance, not voltage. To connect a potentiometer to the auxiliary input port, connect one of the outer potentiometer leads to +5Vdc and the middle lead (wiper) to the potentiometer input pin of your choice.

CAUTION

Do not connect potentiometers to Ground on the Transmitter. This may damage the Transmitter.

The LED may be connected between +5Vdc(red wire) and Ground (black wire) and is intended to serve as a visual indicator to the drivers that the Transmitter is turned on. This can be helpful during a Competition match when power to the Transmitter is controlled by FIRST. The project box makes an ideal mounting point for the LED.

Figure 4.4 shows an example of the proper way to connect a rocker switch, potentiometer, and LED to the auxiliary input port.

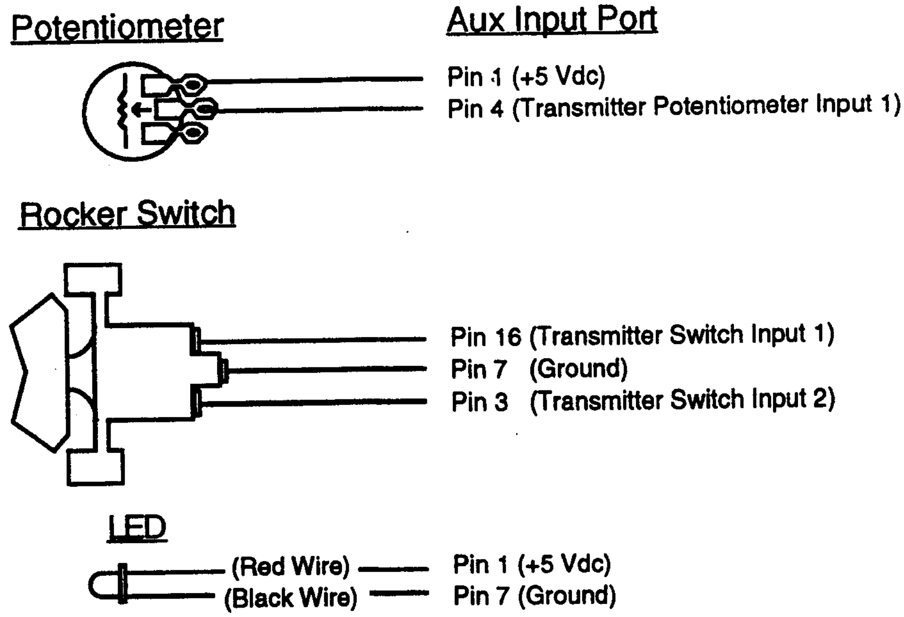

Figure 4.4: Connection Examples for Auxiliary Input Port

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 may 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.

CAUTION

Before opening the Transmitter, the power supply must be disconnected. While the Transmitter is open, be careful to avoid static discharges to the circuit board or connectors. Also, do not allow any foreign particles, especially metal fragments, to get inside the enclosure or onto the circuit board. It is best to open the unit in a clean environment away your robot workarea. Never operate the Transmitter with the cover off. Failure to observe these precautions could result in damage to the equipment.

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 4.5 shows the location of the DIP switches inside the Transmitter. To access the DIP switches, the cover of the Transmitter must be removed. To remove the cover, unscrew the four Phillips head screws on the underside of the Transmitter. The 9 Vdc power supply must be disconnected prior to removing the cover.

NOTE

There are two different designs of the Transmitter board being used in the 1998 Competition. They are functionally identical, but the DIP Switch locations are different, as indicated in Figure 4.5.

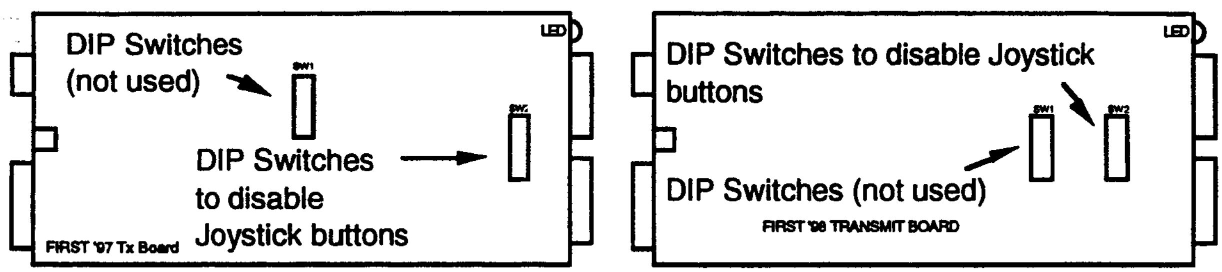

Figure 4.5: Location of DIP Switches Inside Transmitter

4.5 Receiver

The Receiver takes data from the Transmitter, verifies that it has been received correctly, and then forwards it to the control program. The control program takes the data from the Transmitter, reads the on-board sensor inputs, makes decisions based on all the inputs, and sets the PWM and relay outputs.

The connection diagram for the Receiver is shown in Figure 4.6.

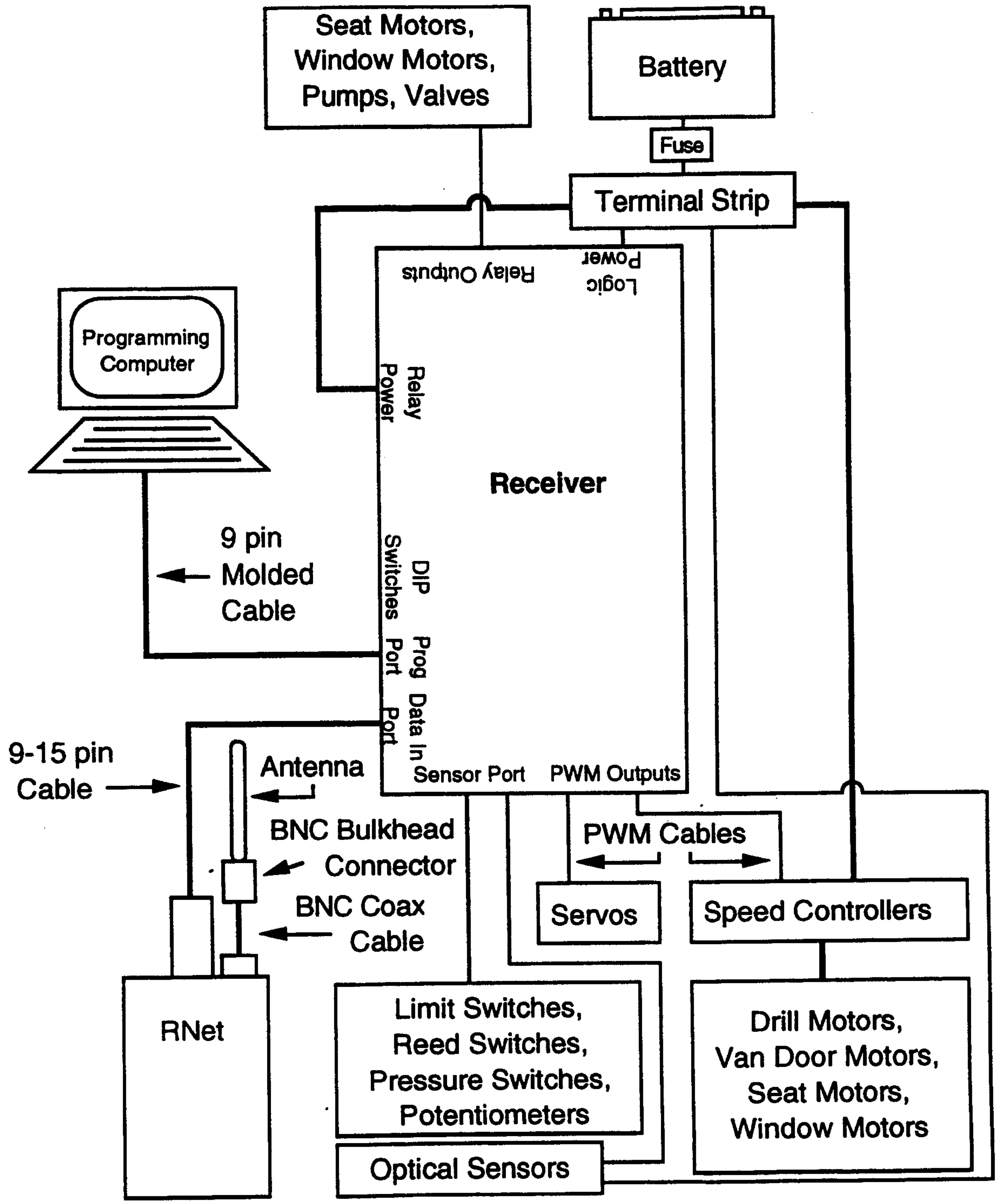

Figure 4.6: Connection Diagram for Receiver

4.5.1 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 program.

There are 16 switch inputs and 4 analog inputs available. The limit switches, reed switches, air pressure switches, and optical sensors may be connected to the switch inputs. The potentiometers may be connected to the analog inputs.

The exact wiring configuration for the switches, potentiometers, and optical sensors connected to the Receiver is not specified. Teams may wire these devices, within the rules as described below, in order to create a custom sensor system on the robot. Table 4.4 shows the pin assignments for the sensor port.

Please exercise caution when wiring the control system. Teams will be required to pay for replacement or repair of devices damaged due to improper wiring.

CAUTION

Do not connect power or any other signals to the switches or switch inputs. Also, be careful to observe the polarity of the power inputs when wiring the control system. Damage to the switches, Receiver, and/or other components may occurr if components are wired incorrectly.

Table 4.4: Receiver Sensor Port Pin Assignments

Pin	Description	Pin	Description
1	Receiver Switch Input 1	14	Receiver Switch Input 2
2	Receiver Switch Input 3	15	Receiver Switch Input 4
3	Receiver Switch Input 5	16	Receiver Switch Input 6
4	Receiver Switch Input 7	17	Receiver Switch Input 8
5	Receiver Switch Input 9	18	Receiver Switch Input 10
6	Receiver Switch Input 11	19	Receiver Switch Input 12
7	Receiver Switch Input 13	20	Receiver Switch Input 14
8	Receiver Switch Input 15	21	Receiver Switch Input 16
9	Ground	22	Receiver Analog Input 3
10	Ground	23	Receiver Analog Input 4
11	Ground	24	Receiver Analog Input 1
12	Ground	25	Receiver Analog Input 2
13	+5Vdc		

In order to connect the switches, potentiometers, and optical sensors to the Receiver, they must be wired to the 25 pin male soldercup connector. The 25 pin connector must then be attached to the sensor port on the Receiver. It is recommended that the plastic hood be used to protect the connections on the 25 pin connector. +12 Vdc power for the optical sensors must be supplied from the terminal strips.

Switch inputs should be closed to Ground or left open to achieve a 1 (on) or 0 (off) state, respectively, within the control program.

CAUTION

Do not connect switches to +5Vdc, it may damage the switches.

The analog input ports on the Receiver read a voltage between 0 to +5Vdc. They are different than the potentiometer inputs on the Transmitter. To connect a potentiometer to the sensor port, connect one of the outer potentiometer leads to +5Vdc, the other outer lead to Ground, and the middle lead (wiper) to the analog input pin of your choice.

To connect an optical sensor to the sensor port, the 4 pin connector on the end of the sensor cable must be removed. Connect the red wire to +12 Vdc on the terminal strip, the black wire to Ground on the sensor port, and the white and green wires to the sensor port switch input pins of your choice. Output characteristics of the optical sensors are described in the manufacturers' specification sheets included in Appendix L.

CAUTION

Do not connect any voltages greater than +5Vdc to the analog inputs on the sensor port. It may damage the Receiver.

Figure 4.7 shows an example of the proper way to connect a limit switch, potentiometer, and optical sensor to the sensor port.

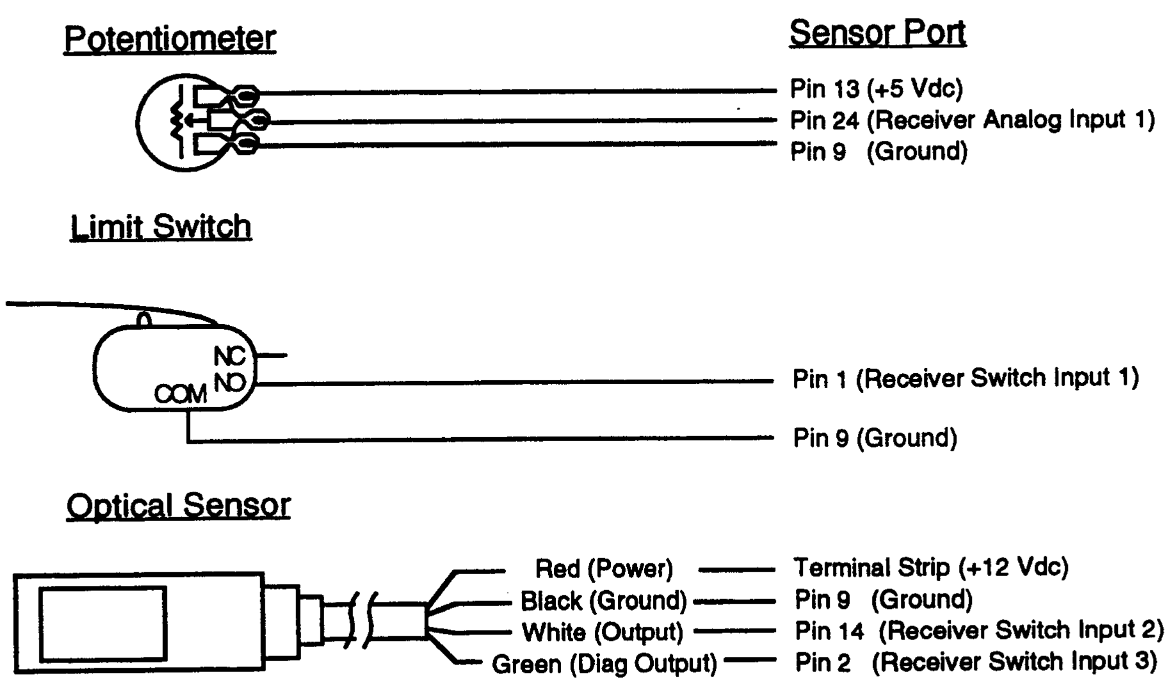

Figure 4.7: Connection Examples for Sensor Port

4.5.2 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.

To operate the robot via wireless control, attach the 9 pin end of a 9-15 pin cable to the Data In port on the Receiver and the other end of the cable the receiving RNet. Next, attach one end of a BNC coax cable to the BNC connector on the RNet, and the other end of the cable to the BNC bulkhead connector. Finally, connect the antenna to the other side of the BNC bulkhead connector.

CAUTION

The antenna should not be connected directly to the receiving RNet. Always use the BNC cable to separate the antenna from the RNet.

Fabricate a small bracket to mount the BNC bulkhead connector to the robot. Be sure to mount the antenna on the robot so that it is pointing up. Avoid placing the antenna behind large metal objects that could shield it from receiving the radio waves from the transmitting RNet. Also, try to avoid placing the antenna or receiving RNet near motors, motor wires, or other sources of electrical noise.

To operate the robot with the tether adapter, disconnect the 9-15 pin cables from the Transmitter and Receiver, replace them with 9 pin molded cables, and join the two 9 pin cables with the tether adapter.

At the beginning of each Competition event, FIRST will collect all RNets from teams to prevent accidental tranmission of data that could interfere with robots on the playing fields. Robots may only be operated via the tether adapter in the pit area. Prior to each match, teams will be assigned a set of RNets based on playing field starting position. Thus, it is important that robots be designed for easy changeover of RNets.

Tip: Locate the RNet so it can be easily removed. The hook and loop fastener on the RNet provides an easy means of attachment to the robot. However, FIRST recommends 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.

4.5.3 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 connected directly 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 Receiver's label.

Tip: It can be difficult to align PWM cables vertically with the PWM output connector when looking at the Receiver from above (through the clear cover). This can result in the connector being placed onto only two of the three pins, which will cause that PWM device not to work (until the situation is corrected). For greater accuracy when connecting PWM cables, be sure to view the Receiver from the side with the PWM outputs.

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 are equivalent. However, 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 4.8 below for details.

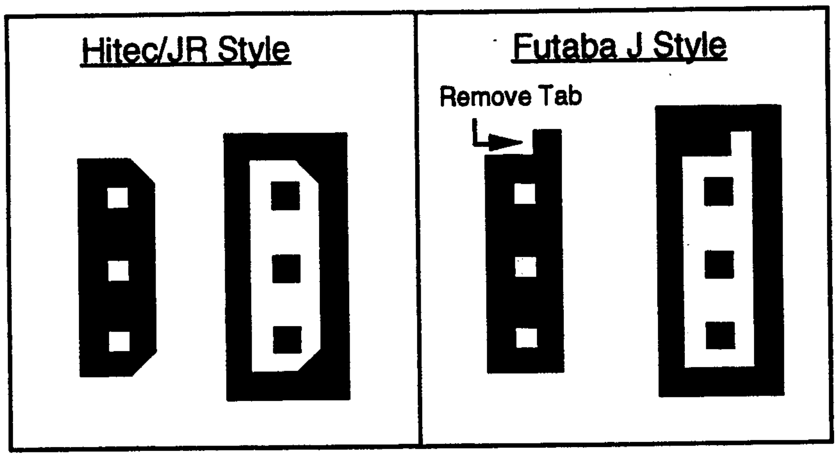

Figure 4.8: Hitec and Futaba-Style PWM Connectors

4.5.4 Relay Outputs

The relay outputs are designed to provide forward and reverse control of the seat motors, window motors, pump, and valves. These outputs may be connected directly to the motor/pump/valve with the appropriate wire, as described in Section 4.3.

CAUTION

Do not connect power from the battery into the relay outputs. Doing so will damage the Receiver.

The relay outputs work by switching the pairs of output pins (F & R) to Ground or +12 Vdc. When both pins are at Ground or both are at +12 Vdc, the output is "off." When pin F is at +12 Vdc, and pin R is at Ground, the output is "forward." When pin F is at Ground and pin R is at +12 Vdc, the output is "reverse."

Power and Ground for the relay outputs are routed from the Relay Power connector. If +12 Vdc and Ground are not connected to the Relay Power connector, output devices connected to the relay outputs will not function.

Tip: To achieve control of both solenoids on the double solenoid valve and use only one relay channel, use the two diodes provided in the Kit to route power to one solenoid at a time. Figure 4.9 shows the schematic for this arrangement.

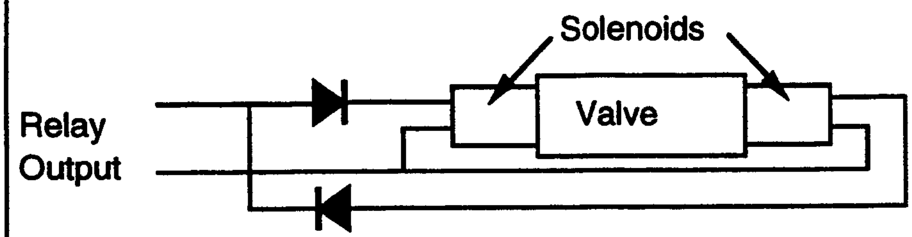

Figure 4.9: Use of Diodes with Double Solenoid Valve

4.5.5 Status LEDs

The Receiver has a number of status LEDs that are useful in debugging problems that may arise. Below is a description of the function of these LEDs.

D5-8 and D13-16 are bi-color (green or red) LEDs that indicate the status of the relay outputs. The mapping of LED to output channel should be obvious. For each channel, the LED will turn green if the forward pin is high and the reverse pin is low, or red if the reverse pin is high and the forward pin is low. If both pins are low or high the LED will be dark. The LED will also fail to light if power and ground are not connected to the Relay Power connector, or if there are blown fuses on that relay channel.

D17-20 are yellow LEDs that indicate whether power is available at various sections of the board. If any of these LEDs fail to light up when +12 Vdc power is applied to the Logic Power input on the Receiver, there is a problem and you should contact FIRST. D17 indicates 12 Vdc is connected to the Logic Power input at the proper polarity. D18 indicates +12 Vdc is past the 3.15A input fuse (F17) and is available for the relay coils (but not relay outputs), 12->7.5 Vdc converter (RNet power) and 12->5 Vdc converters (logic, PWM & sensor port power). D19 indicates +5 Vdc is coming out of the Power Trends 12->5 Vdc converter. D20 indicates +5 Vdc is past the 3.15A fuse (F22) and is available for the PWM outputs and sensor port.

D25 is a bi-color LED that indicates the status of data reception. D25 should blink green each time an uncorrupted packet of data is received from the Transmitter. D25 will blink red if corrupted data is received, and will stay off when data is not being received. When running the default control program, D26 will blink green each time data is passed to the control program. The function of D26 can be changed when running a user control program.

D31-33 are red LEDs that will light if the Receiver detects various problems with the control system. D31 will light if too much of the data being received is corrupted. D32 will light if there is a problem sending data to the control program. D33 will light if the delay between receiving packets of uncorrupted data is too long. If either D31 or D33 light, it is an indication that there is a problem somewhere in the data transmission or reception hardware (RNets, antennas, data cables, 9-15 adapters, and/or tether adapters). If D32 lights, it could be due to a user control program that has crashed or is taking too long to respond, incorrect DIP switch settings on the Receiver, or a problem with the Receiver circuit board. Loading a user control program into the Receiver while it is receiving data will also cause D32 to light, but this should not be interpreted as an error. If any of these problems are detected, corrective action should be taken. Otherwise, the robot may fail to operate properly during a Competition.

4.5.6 Fuses

There are a number of replaceable fuses in the Receiver that are designed to protect it from damage. If you discover a blown fuse, carefully check the wiring of the entire electrical system and correct any faults that are discovered. Remember that fuses do not blow themselves. Replace fuses only with fuses of the same rating. If a replacement fuse blows, it means there is still a problem. Do not bypass the fuse -- fix the problem.

Teams are encouraged to replace blown fuses themselves rather than sending the Receiver back to the FIRST for repair. Full fuse specifications are provided below. For convenience, part numbers for ordering the fuses from Digi-Key are also provided. Contact information for Digi-Key is included in the Vendor Contact List in Appendix C. Other electronic part supply companies are likely to carry these fuses too.

Table 4.5: Receiver Fuse Specifications

Fuse	Description	Manufacturer	Mfg. Part #	Digi-Key Part#
F1-16	20A ATM Mini Auto	Littlefuse	297020	F993-ND
F17-18	3.15A TR5 Sub-Mini	Wickman	19373-124-K	WK3024BK-ND
F19-27	1.25A TR5 Sub-Mini	Wickman	19373-050-K	WK3050BK-ND

Fuses F1-16 protect the relay outputs from excessive current draw. Each relay output pin is fused. If either fuse of a relay output channel is blown, the channel will not work.

F17 limits the current coming into the logic power connector in the event of a short circuit somewhere on the board. If F17 is blown, the Receiver board will not function at all. If F17 blows, there may be a loose piece of metal causing a short circuit somewhere inside the Receiver enclosure.

F18 limits the current supply to the +5 Vdc pins on the PWM outputs and sensor port. Servos, potentiometers, and the optical switches will not function if this fuse is blown.

F19-26 protects each ground pin on the PWM output connector. Servos will not function and speed controllers may function erratically if connected to a PWM output with a blown ground fuse.

F27 protects the ground connection on the Data In port. If this fuse is blown, the Receiver will be unable to receive data from the Transmitter. If this fuse blows, it is probably because +12 Vdc has been shorted to the metal case of the RNet, which is connected to ground.

4.6 Programming the Receiver

4.6.1 Control Programs

The Receiver is supplied with a default control program in order to help get the robot up and running quickly. The functionality of the default control program is described below. If more sophisticated control of the robot is desired, then a custom program, known as the user control program, must be written. In order to facilitate the creation of a user control program, source code for the default control program is provided.

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 user control program.

DIP switches on the side of the Receiver are used to select which control program (default or user) is running, and to reset the Receiver in the event of a problem. Table 4.6 shows the Receiver DIP switch settings.

Table 4.6: 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.

The Receiver is designed to prevent the default control program from being overwritten.

In order to program the Receiver, a 9 pin cable must be connected from the serial port of a PC to the Programming Port on the Receiver, the DIP switches must be set for the user control program and power must be connected to the Logic Power input. The programming software is included on the disk labeled "BASIC Stamp" from Parallax, Inc. The programming utility STAMP2.EXE is located in the \STAMP2 subdirectory. The source code for the default control program, RXSLAVE.BS2, is on the disk labeled "Control Program Source Code - 1998" from FIRST. Complete documentation for the STAMP2 program and the PBASIC programming language is provided in the manual entitled "BASIC Stamp Manual Version 1.8" from Parallax, Inc. With the exception of the source code for the default control program, the programming utility and manual can also be obtained via the Internet from Parallax, Inc. at www.parallaxinc.com or ftp.parallaxinc.com. FIRST will make the default control program available to teams via the FIRST web site at www.usfirst.org.

Tip: The documentation files on www.parallaxinc.com are in Adobe's Portable Document Format (PDF). Programs to view these files are available over the Internet for free from Adobe at www.adobe.com.

4.6.2 Input/Output Map

Table 4.7 shows the mapping of Transmitter and Receiver inputs to Receiver outputs when the default control program is running. It also repeats the input pin information and shows what variables in the default control program are used to store the various input values.

Table 4.7: Input to Output Mapping of Default Control Program

Input TX = Transmitter RX = Receiver	Input Pin	Control Program Variable	Receiver Output
TX Joystick 1 - X Axis	-	x1	PWM1
TX Joystick 1 - Y Axis	-	y1	PWM2
TX Joystick 2 - X Axis	-	x2	PWM3
TX Joystick 2 - Y Axis	-	y2	PWM4
TX Potentiometer 1	4	tx_pot1	PWM5
TX Joystick 1 - Thumbwheel	-	wheel1	PWM6
TX Potentiometer 2	19	tx_pot2	PWM7
TX Joystick 2 - Thumbwheel	-	wheel2	PWM8
TX Switch 1	16	tx_sw1	Relay Output 1 (F)
RX Switch 1 forces off	1	rx_sw1	
TX Switch 2	3	tx_sw2	Relay Output 1 (R)
RX Switch 2 forces off	14	rx_sw2	
TX Switch 3	6	tx_sw3	Relay Output 2 (F)
RX Switch 3 forces off	2	rx_sw3	
TX Switch 4	18	tx_sw4	Relay Output 2 (R)
RX Switch 4 forces off	15	rx_sw4	
TX Switch 5	15	tx_sw5	Relay Output 3 (F)
RX Switch 5 forces off	3	rx_sw5	
TX Switch 6	2	tx_sw6	Relay Output 3 (R)
RX Switch 6 forces off	16	rx_sw6	
TX Switch 7	5	tx_sw7	Relay Output 4 (F)
RX Switch 7 forces off	4	rx_sw7	
TX Switch 8	17	tx_sw8	Relay Output 4 (R)
RX Switch 8 forces off	17	rx_sw8	
TX Switch 9	12	tx_sw9	Relay Output 5 (F)
RX Switch 9	5	rx_sw9	
TX Switch 10	24	tx_sw10	Relay Output 5 (R)
RX Switch 10	18	rx_sw10	
TX Switch 11	11	tx_sw11	Relay Output 6 (F)
RX Switch 11	6	rx_sw11	
TX Switch 12	23	tx_sw12	Relay Output 6 (R)
RX Switch 12	19	rx_sw12	
TX Switch 13	10	tx_sw13	Relay Output 7 (F)
RX Switch 13	7	rx_sw13	
TX Switch 14	22	tx_sw14	Relay Output 7 (R)
RX Switch 14	20	rx_sw14	
TX Switch 15	9	tx_sw15	Relay Output 8 (F)
RX Switch 15	8	rx_sw15	
TX Switch 16	21	tx_sw16	Relay Output 8 (R)
RX Switch 16	21	rx_sw16	
RX Analog Input 1	24	rx_analog1	Ignored
RX Analog Input 2	25	rx_analog2	Ignored
RX Analog Input 3	22	rx_analog3	Ignored
RX Analog Input 4	23	rx_analog4	Ignored

In general, with the default control program PWM outputs correspond to joystick and potentiometer inputs on the Transmitter, and relay outputs are turned on (+12 Vdc) if the corresponding switch inputs are connected to ground (1), or relay outputs are turned off (Ground) if the corresponding switch inputs are disconnected (0). However, in the case of Receiver switch inputs 1-8, this behavior is reversed and these switch inputs take precedence over Transmitter switch inputs 1-8 in order to act as directional stop overrides.

4.6.3 Programming Language

All control programs running on the Receiver must be written in PBASIC, a dialect of the BASIC programming language. This language was selected because it is fairly easy to learn, use, 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 user control program is used, the team assumes full responsibility for insuring that the code works as expected.

NOTE

It must be clearly understood that teams are responsible for any software bugs introduced into the control program when using a user control 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.

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 user control program. It is recommended that the RXSLAVE.BS2 file be copied, and that the copy be used to write any user control software. This way, the original file will always be available as a backup.

4.6.4 User Program Examples

Below are two simple examples of how the default control program can be modified to provide custom functionality.

Example #1 - Coordinated Mode

Many teams wish to drive their robots with only 1 Joystick, leaving the other joystick for the other driver to operate various mechanisms. The most convenient scheme for single joystick driving control is to have the Y-axis control speed, while the X-axis controls turning rate. This can be accomplished with a simple modification to the default control program. Source code to do this is provided below:

```
' This example allows Joystick 1 to easily steer a robot with tank-style steering by
' commanding speed with the Y axis and commanding turning rate with the X axis.
' The left side drive motor should be controlled by PWM1, and the right side drive
' motor should be controlled by PWM2.

Serout SSC, SSCBAUD, [SSC_CMD, PWM1, (((2000 + y1 - x1 + 127) Min 2000 Max 2254) - 2000)]
Serout SSC, SSCBAUD, [SSC_CMD, PWM2, (((2000 + y1 + x1 - 127) Min 2000 Max 2254) - 2000)]
'  Serout SSC, SSCBAUD, [SSC_CMD, PWM1, x1]  ' This line must be commented out
'  Serout SSC, SSCBAUD, [SSC_CMD, PWM2, y1]  ' This line must be commented out
```

Tip: PBASIC stores numeric values as positive integers. Byte variables have a value range of 0-255. Word variables have a value range of 0-65535. When performing a calculation that would ordinarily result in a negative number, it will instead wrap around to a very high number, because it knows of nothing less than 0. The example code above shows one possible way to get around this limitation by adding 2000, doing a MIN 2000, and then subtracting 2000 at the end.

Figure 4.10 below shows the resultant outputs from PWM1 and PWM2.

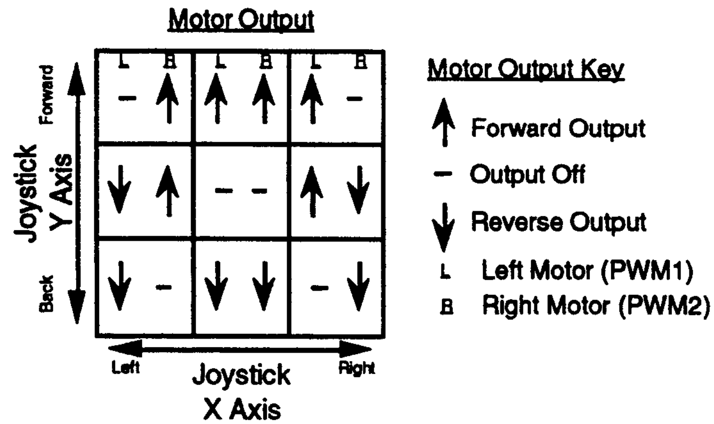

Figure 4.10: Coordinated Mode Motor Output vs Joystick Position

Tip: The x and y-axis values for each joystick will reach maximum when the joystick handle is leaning toward the upper-left corner. The thumbwheels reach maximum when rotated fully forward.

Example #2 - Coordinated Mode with Joystick Sensitivity Scaling

Several teams have asked for hints on how to change the sensitivity of the joysticks when using "coordinated mode". There are two basic strategies:

1. The easy method: Don't change the sensitivity, just limit the maximum output values. This can be done by a simple adjustment to the Min and Max part of the line. Raise the Min above 2000 to slow down the

maximum reverse speed, and lower the Max from 2254 to slow down the maximum forward speed. For example:

```
(((2000 + y1 - x1 + 127) Min 2020 Max 2234) - 2000)
```

2. The harder but smoother method: Scale the output value down. Take the whole (((...))) part, multiply by a fraction, and add a constant to keep it centered. For example:

```
(( (((2000+y1-x1+127) Min 2000 Max 2254) -2000) * 84/100) + 20
Max 254)
```

Tip: When scaling a PWM output, remember that the neutral point (off) is approximately 127. Therefore, you will need to add a constant to the scaled value to keep it centered. Also, remember that PBASIC math is integer-based, so always multiply before you divide to minimize rounding errors.

Please note that both strategies require the speed controllers to be calibrated prior to modifying the joystick sensitivity. Otherwise, the speed controllers will scale the motor outputs back to maximum reverse and maximum forward and the scaling will appear to have no effect.

4.6.5 Programming the PWM Outputs

The PWM output signals are generated by a chip called the Serial Servo Controller (SSC). Commands in the control program tell the SSC what values to output. For example:

```
Serout SSC, SSCBAUD, [SSC_CMD, PWM1, x1] ' Update PWM outputs
```

This command sets PWM1 to match the position of the X axis on Joystick 1.

The range of PWM output values which may be sent to Serial Servo Controller is 0-254. 255 is reserved as the Command Prefix (SSC_CMD). The Transmitter will never give a joystick axis, joystick wheel, or potentiometer input reading higher than 254, so it is safe to pass those values straight to the SSC.

When sending a calculated value to the SSC, it is wise to use the Min and Max operators to limit the calculation to appropriate values. The example code in Section 4.6.4 shows this.

Tip: The SSC only accepts data for one output at a time. Thus, it takes 8 SSC commands to update all 8 PWM outputs. To speed up the control program, comment out (put a single-quote at the beginning of the line) commands corresponding to unused PWM outputs.

The SSC, and thus the PWM outputs, is only enabled when uncorrupted data is being received from the Transmitter. This allows the robots to be shutdown remotely. However, whenever the SSC is disabled, it is reset. The default mode for the SSC after a reset is to set all PWM outputs to 127. Thus, it is important to update the PWM values quickly after receiving data.

4.6.6 Programming the Relay Outputs

In the control program, the variable "relays" contains 16 bits that are used to set the state of the relay outputs. Each bit corresponds to a relay output pin. The aliases rly1_fwd, rly1_rev, rly2_fwd, etc. show which bit corresponds to which output pin, and can be used to easily address individual pins. A bit equal to 1 corresponds to an output pin at + 12 Vdc, while a bit equal to 0 corresponds to an output pin at GND.

The variable "tx_sw" contains 16 bits that correspond to the state of the switch inputs on the Transmitter's Auxiliary Input Port and Joystick Ports. Each bit corresponds to a switch input. The aliases sw1_fwd, sw1_rev, sw2_fwd, etc., in conjunction with Table 4.7, show which bit corresponds to which input pin. A bit equal to 1 corresponds to a closed (grounded) switch input, while a bit equal to 0 corresponds to an open (unconnected) switch input.

Each time the control loop runs, "relays" is initialized to the state of the switch inputs on the Transmitter by the lines:

```
' Set relays to match TX switches
relays = tx_sw
```

This allows the robot drivers to control the relay outputs by pressing switches on the joysticks and rocker switches on the project box.

The variable "rx_sw" contains 16 bits that correspond to the state of the switch inputs on the Receiver's Sensor Port. Each bit corresponds to an input pin. The aliases rx_sw1, rx_sw2, rx_sw3, etc., in conjunction with Table 4.7, show which bit corresponds to which switch input pin. A bit equal to 1 corresponds to a closed switch input, while a bit equal to 0 corresponds to an open switch input.

Each time the control loop runs, "rx_sw" is updated by the following lines:

```
' Read Switch Inputs into rx_sw
Gosub ReadSwitches
```

After "relays" is initialized, but before the relay outputs are actually updated, the data in "rx_sw" is used to modify the behavior of the relay outputs in the following lines:


```
' Use 1st 8 RX switches (rx_sw1-8) as STOP switches for Relays 1-4
relays.lowbyte = relays.lowbyte &~ rx_sw.lowbyte

' Use 2nd 8 RX switches (rx_sw9-16) as GO switches for Relays 5-8
relays.highbyte = relays.highbyte | rx_sw.highbyte
```

In the first equation, "relays.lowbyte" addresses the first 8 bits of "relays", which correspond to the forward and reverse pins for the first 4 relays, while "rx_sw.lowbyte" contains the state of the first 8 Receiver switch inputs. A logical (bit for bit) AND NOT (&~) operation is performed and the results are stored back in "relays.lowbyte". This means that bits in "relays.lowbyte" that are off (0) are left off, and bits that are on (1) are left on unless the corresponding bit in "rx_sw.lowbyte" is also on. This translates to leaving off relays off, and on relays on unless a corresponding Receiver switch input is closed. Thus, the first 8 switch inputs on the Sensor Port can be used as safety overrides to force relays 1-4 off.

In the second equation, "relays.highbyte" addresses the last 8 bits of "relays", which correspond to the forward and reverse pins for the last 4 relays, while "rx_sw.highbyte" contains the state of the last 8 Receiver switch inputs. A logical OR (|) operation is performed and the results stored back in "relays.highbyte". This means that a bit in relays.highbyte will end up on if it starts on or if the corresponding bit in rx_sw.highbyte is on. Otherwise, it will stay off. Thus, the last 8 switch inputs on the Sensor Port can be used to force relays 5-8 on.

Once the values for the relay states have been computed, the outputs are updated by writing the data contained in "relays" to a set of shift registers that actually control the relays. This is done in the following line just before the end of the loop:

```
' Set Relay Outputs
Gosub SetRelays
```

The relay outputs on the Receiver are only enabled when data is being received from the Transmitter. This allows the robots to be shutdown remotely. If data reception is interrupted and then restored, the relays will resume their prior state automatically.

4.6.7 Receiver CPUs

The Receiver has two CPUs, the Master CPU and the User CPU. Both are Basic Stamp 2 CPUs. The Master CPU reads and validates the data from the Transmitter, passes uncorrupted data to the User CPU, and keeps the outputs from shutting down as long as uncorrupted data is being received. The User CPU runs the control program.

When power is first applied to the Receiver, or the battery voltage gets too low and there is a brownout on the robot, or the Reset DIP switch is toggled, the CPUs are reset. When this happens, all RAM variables are erased, and the control program restarts at the beginning.

If the control program takes a long time executing instructions within the loop, it will start to miss data coming in from the Master CPU. This is ok, but will result in an increased response time for driver and sensor inputs. If the control program takes a really long time (more than 0.10 seconds in the loop) or crashes, the Master CPU will consider this an error and perform the following sequence of actions:

- Disable Relay and PWM outputs
- Turn LED D32 On
- Resume waiting for data from Transmitter and attempting to communicate with control program

Relay and PWM outputs will not be re-enabled until communication with the control program has been reestablished.

4.7 Output Devices

4.7.1 Speed Controllers

All teams are required to make the following modifications to the speed controllers:

- Disconnect the red (middle) lead of the 3-wire PWM cable coming out of each Tekin speed controller. This can be done by carefully pulling the pin out of the connector or by physically cutting the red wire. Insulate the pin or ends of the wire with electrical tape or shrink wrap tubing
- Turn on the Battery Eliminator Circuit (BEC) on each Tekin speed controller. This is done by setting the switch coming out of each speed controller to the on position. The on position is indicated by the small tab molded onto the side of the red plastic switch housing.

CAUTION

Failure to make the above modifications to the speed controllers could lead to faulty operation of the Receiver, loss of control of the robot, and/or damage to the control system.

Refer to the Tekin REBEL Owner's Manual for instructions on connecting the speed controllers to the battery and motors. Two capacitors, included with each speed controller, are to 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. Additional capacitors of the same rating (0.1 mfd) may be purchased to replace these should they be damaged. They do not have to be from the same manufacturer.

For protection, one 30A circuit breaker must be installed in series with each drill/van door motor and speed controller. Do not disable the circuit breaker by connecting its terminals together. 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 one to three seconds.

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. A 12V muffin fan has been included in the Kit primarily for added protection against overheating of speed controllers and/or drill motors. It is recommended this fan be installed 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.

To help insure ease of control, both the joysticks and the speed controllers should be calibrated. Joystick calibration is especially important when using the "Coordinated Mode" steering as mentioned in section 4.6.4. In this mode, the formulas used expect joystick 1 to be centered properly so that x1=127 and y1=127 when the joystick handle is physically centered.

To calibrate the joysticks, perform the following steps:

1. Set the Receiver to run the default control program.
2. Attach both joysticks to the Transmitter and visually center the trimmers for the X and Y axes.
3. Attach the servos to PWM1 and PWM2.
4. Move joystick 1 to the four corners and observe the minimum and maximum positions of the servos.
5. Locate the center of the range of movement of each servo arm.
6. Release the handle of joystick 1 and adjust the X and Y trimmers so that the servos are centered.
7. Joystick 1 is now calibrated. Tape the X and Y trimmers to prevent further adjustment.
8. Connect the servos to PWM 3 and 4, and repeat steps 4-7 with joystick 2.

Calibrating the speed controllers ensures that they will achieve maximum output in forward and reverse when the joystick is at the ends of travel, no output when the joystick is centered, and a proportional output when the joystick is not in the center or at either extreme. Also, the reverse delay (braking delay when switching from forward to reverse) can be set, or reverse can be disabled entirely. Instructions for calibrating the speed controllers are included in the Tekin REBEL Owner's Manuals.

NOTE

The speed controllers should be recalibrated any time the joystick calibration is changed.

4.7.2 Drill Motors & Gearboxes

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 heavy robot. 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.

4.7.3 Seat, Window, and Van Door Motors

The seat, window, and van door motors contain one worm gear reduction stage and, in the case of the seat motors, a positive temperature coefficient (PTC) thermistor for overload protection. As the seat motors become 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. All motors, even those without a PTC device, will loose output power as they heat up. 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.

4.7.4 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 of 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.

4.8 Batteries and Chargers

Teams are responsible for managing the power consumption of their robot and for ensuring that their batteries are sufficiently charged to compete in each two minute match. This means that teams must charge their batteries at their pit stations at each Competition event.

For instructions on charging the batteries, please refer to the battery charger documentation included in the Kit.

WARNING

A warm battery should be allowed to cool before 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. Return the damaged battery to FIRST so it can be recycled properly.

It is estimated that each SLA battery can store sufficient energy to power a robot for at least 5 two minute matches. Thus, it should not be necessary to swap batteries after each match.

Due to the short delay between matches upon reaching the quarter-finals rounds on the final day of each Competition event, FIRST will provide a freshly charged battery to each remaining competitor at each level of finals. For example, a team making it all the way to the finals would receive a freshly charged battery at the start of the quarter-finals, a second freshly charged battery at the start of the semi-finals, and a third freshly charged battery at the start of the finals.

To connect the battery to the rest of the control system, always use the ring terminal contacts provided in the kit. In addition, it is highly recommended that the battery mount provided in the kit be used to secure the battery to the robot.

When connecting the battery, be very careful to observe the proper polarity in order to prevent damage to control system components.

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

During any Competition event, the robots may only be powered by a single 12 Vdc SLA battery supplied by FIRST. These batteries may only be charged through the normal operation of the battery charger provided by FIRST.