

VOLUME I:
**OPERATIONS
MANUAL**

PROJECT:
EMFFORCE

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Space Systems Product Development
Professor David Miller

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G	METROLOGY SYSTEM DESIGN	ERROR! BOOKMARK NOT DEFINED.
H	STRUCTURES AND PACKAGING	ERROR! BOOKMARK NOT DEFINED.
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Contributors

Structure and Power:

Geeta Gupta (GG)
Amy Schonsheck (ALS)
Tim Sutherland (TAS)

Electronics:

Stephanie Slowik (SS)
Erik Stockham (ESS)
Margaret Sullivan (MS)
Jennifer Underwood (JEU)

Actuation:

Jesus Bolivar (JB)
Melanie Woo (MSW)
Will Fournier (WF)
Lindsey Wolf (LW)

Formation Flight:

Amilio Aviles (AA)
Andre Bosch (AB)
Oscar Murillo (OM)
Leah Soffer (LS)

Forward (JEU)

In coming years, the development of formation flight technology may prove a significant force in the race to provide new and improved satellite mission capabilities. Formation flight technology enables a cluster of satellites to maintain a specified configuration while in orbit about the Earth. The MIT SSL SPHERES project demonstrated the initial feasibility of this technology via thruster actuation. The MIT SSL ElectroMagnetic Formation Flight Of Rotating Clustered Entities (EMFFORCE) project now seeks to extend the work done by SPHERES to demonstrate the viability of utilizing controlled electromagnetic fields to maintain and adjust satellite formations.

There exist many motivations for formation flight architectures. The major benefits include: separation, “virtual” spacecraft, modularity, multiple missions, and mission evolution. Separation means that the spacecraft can be separated at large distances. Keeping the satellites apart from one another prevents the disasters inherent in maintaining “all of your eggs in one basket.” Furthermore, it enables new technology such as interferometry by increasing the angular resolution of onboard imaging equipment. Flying satellites in formation creates a “virtual” spacecraft since the formation is designed to accomplish the same mission that a larger, single spacecraft would. Not only is there a reduction in the overall cost of the mission with respect to launching a single satellite, but formation flight facilitates easier packaging, launching, and deployment of the member satellites. Modularity and interchangeability of the spacecraft imply that a single failure will not end the mission. Given that inter-spacecraft interfaces such as communications, control, and metrology are soft, a failing spacecraft can be removed from the formation and replaced with little effort. Formation flight enables multiple missions to be performed using the same cluster of satellites since the array can self-arrange to reflect a multitude of mission requirements. Furthermore, next generation spacecraft can be launched and integrated into the array, gradually evolving the formation’s capabilities as time and technology permit.

Electromagnetic actuation provides several additional capabilities to the flight formation concept. Primarily, should electromagnetic actuation prove feasible, it would reduce, if not eliminate entirely, the need for thrusters on formation flying satellites. Eliminating thrusters decreases the amount of consumables on board the spacecraft, leading to longer life. Thrusters produce pollution that can damage sensitive equipment via ablation. Furthermore, thrusters can generate a pollution haze that can cause radiative contamination of sensitive equipment and optics. Since electromagnetic actuation does not result in optical hazing or contamination, optical communication between satellites may finally be possible. Electromagnetic actuation can control the relative positioning of the satellites required by formation flight architectures. Thrusters are only capable of controlling the absolute positions of satellites.

Mission Statement (ESS)

Understanding the benefits derived from an operable EMFF system and the challenges that must first be overcome, the EMFFORCE project set about accomplishing the mission:

Demonstrate the feasibility of electromagnetic control for formation flying satellites.

Project EMFFORCE aims to operate a formation flying testbed that represents a real-world system. The mission statement also implies that a 2-D operational testbed must be translatable to a 3-D operational testbed. Electromagnetic control suggests the design and implementation of a controller using no thrusters but instead coupled electromagnetic forces with angular momentum storage.

Purpose of this Document (ESS)

Volume I: OPERATIONS MANUAL is designed for the operator who will continue to use the current EMFFORCE system in accordance with the mission. It provides details for the setup, operation, and troubleshooting of all EMFFORCE subsystems. The OPERATIONS MANUAL provides a quick reference guide to the current system and operational lessons learned as of May 2003. For a detailed description of subsystem design analyses, specifications, and fabrication processes, refer to Volume II: DESIGN APPENDIX.

1 General Operations Considerations

1.1 Laboratory Safety

The objective of the EMFFORCE safety program is to protect staff, equipment, and the facility from preventable hazards. In general, simply being careful and using common sense can prevent most mishaps before they happen.

1.1.1 Short circuits

The metal table surface creates a significant short circuit hazard. Wire leads and battery casings frequently short across the table, creating sparks that can injure a person or destroy sensitive microelectronics. Never place batteries or power sources on the metal air table surface.

1.1.2 Glass care

The glass surface needs to be protected from scratches and chips that can degrade its performance. LN2 spills may also cause thermal stress in the glass and lead to cracking.

2 Structure Assembly Procedure

When assembling the vehicle it is important to perform certain steps before others.

Below are instructions to assemble the EMFFORCE vehicle. The RWA mount, base plate, U shaped braces, and L brackets were all cut using the water jet cutter, operated using OMAX control files. These files are available in the Drawings Folder of the OPSMAN directory.

2.1 Structure Assembly (GG)

1. Attach the U-shaped braces to base plate. These braces are attached to the plate with 10-32 ½” screws. The tall braces are mounted across each other for the smaller ring to sit on, and the shorter braces are also mounted across each other for the larger ring to sit on.
2. Next the air carriage pucks must be attached to the ring. Please see Appendix D for more instructions on puck attachment.
3. Using foam as padding place the larger electromagnet on the set of shorter braces and fasten in place with hose clamps. See Figure 2.4. Again using foam as padding, carefully place inner ring inside of outer ring, on the taller set of braces and fasten in place with hose clamps. Be sure to assemble the electromagnets so that the flat part of each ring is aligned horizontally at the top. The power leads on both rings should be over the square U-shaped bracket.
4. Once the rings are in place the L brackets that hold up the RWA mount may be epoxied in place. These brackets are to be mounted at a height of 355 mm from the bottom of the assembled electromagnets. In order to fasten these brackets securely to the rings, first epoxy them in place and then add a layer of fiberglass strips for added rigidity. Note that these attachments will take 24 hours to dry. After the L bracket attach points have cured the RWA mount may be fastened to the L-brackets and leveled using 6-32 nuts and bolts.
5. At this point the RWA, electronics mount, batteries, and remaining air carriage may be placed on the vehicle in any order. The metrology and communications subsystems can also be integrated onto the physical vehicle once the LN2 tank is in place.

2.2 Air Carriage Assembly (AS)

Please see Appendix D for visual aids in identifying parts and their locations.

1. Remove the large plastic adapter that comes standard on the bottomline kit if it hasn't been already. Connect the 1/8” end of the reducing coupling to the end of the bottomline hose and connect the ¼” nipple to the other end.
2. Connect one ¼” tube adapter to the output of the regulator. Connect the pressure gauge (if desired) to the gauge port of the regulator. Connect the nipple of the bottomline assembly to the input of the regulator.

3. For each puck, place finger spring over gas port. Connect one 1/8" tube adapter to the port.
4. Insert each puck into place in the base ring. Attach with long 6-32 screws. (Note: this is not a rigid attachment.)
5. Connect one 1/4" tube adapter, three 1/8" tube adapters, one 1/4" hex plug, and one 1/8" hex plug into the ports of the manifold.
6. Place manifold in desired location on base ring. This should be right next to the spot for the CO2 tank.
7. Measure appropriate tube length required for going from the manifold to the farthest puck. Cut three tubes of this length. Press one end of each tube into a 1/8" fitting in the manifold, and the other end into the puck fitting.
8. Cut another short length of tube and connect the 1/4" manifold fitting to the output of the regulator.
9. When ready for operation, install the tank in its water bath and connect tank to bottomline. See operation instructions below.

(Note: All connections use Teflon tape to seal them. Make sure when wrapping with Teflon tape that the tape is wrapped clockwise over the top of the fitting as the threaded end points towards you to prevent the tape from bunching up.)

2.3 Air Carriage Operation (AS)

To operate the EMFFORCE air carriage, just follow these quick and easy steps:

1. Fill the water bath container to the marked fill line with hot tap water. Place the water bath on its Velcro spot on the base ring.
2. Connect the tank to the bottomline. There are two types of tank valves in use for this project. One is a standard pin valve (Figure 2.8). Be aware that this type of valve will engage as soon as it is connected to the bottomline, so be ready to move quickly and begin testing right away. The other type (Figure 2.9) includes an on/off valve controlled with a knob. One may connect this tank completely and then activate the airflow anytime after that.



Figure 2.8. Standard pin valve.



Figure 2.9. Valve with on/off .

3. Place the tank into the water bath.
4. If appropriate, turn the valve to on when ready for test to commence.
5. Manually set pressure to desired level using the knob on the regulator.

3 Electronics, Wiring, and Power

3.1 Overall Electronics Board Design Specifications (SS)

Three Electronics boards were manufactured by Advanced Circuits. The boards are 2-layer prototyping boards made of 0.062” thick FR4 and has dimensions of 13.2cm x 10.5cm.

3.2 How to Load software onto the Electronics Board (SS)

The overall Electronics board is depicted in the OrCAD Layout drawing, Figure 3-1. First, the TT8 computers must be attached to the board itself. Two Motorola TT8cs shall connect to the electronics board via one 16-pin header and one 20-pin header for each computer. The Tattletale computers should fit snug on the board as per the TT8/header connection on Onset Computer’s IO-8 prototyping board. Let the “top” of the board be defined as the portion with the screw terminals and the “bottom” be the portion with the RS232 serial ports. On the top of the board, there are also 6 3-pin headers perpendicular to the 16-pin headers. The rightmost of these pin headers for each Tattletale (X and Y according to the following diagram) connect to the IRQ3/MCLR/DGND pins on the Tattletales. When loading to the FLASH memory, a female header pin must connect the IRQ3 and MCLR pins. This connection should be removed upon successful code loading onto the FLASH memory. No such connection is needed when loading code to the RAM.

Four RS232 serial ports are located on the bottom of the tattletale. Ports U and W are used for the code loading of the Metrology and Avionics code, respectively. Ports T and V are designated for TT8-to-TT8 communication. A male-to-male serial cable must be connected to these two ports so that the Metrology and Avionics computers can communicate.

To load software, connect the computer to serial port U for Metrology and W for Avionics using a serial cable. Ensure that the AA batteries are fully charged, and then connect them to the Voltage Regulators as described in the Power connection section. Then connect the leads from the Voltage Regulator Board into screw terminals A and B of Figure 3-1 to supply Power and Digital Ground, respectively. Load code as specified in the Tattletale8C manual (see Appendix C).

In order to reset the system and allow it to accept new code, it may be necessary to hard reset the avionics. This must be accomplished by disconnecting the batteries from the voltage regulator board; the TT8 will not reset when connected to a live avionics system, even with the main power unplugged. The user must turn the gyro on prior to reconnecting the power supply.

3.3 Hardware Connections/Integration (SS)

All input/output pins and channels for the Tattletale computers are wired to screw terminals (screw terminal part specification to be found in Appendix C). Leads from each piece of hardware are simply placed in the terminal and fastened down with the screws.

The following are the board part designations according to Figure 3-1. Simply connect a lead wire(or in the case of a serial port, a serial cable) from the hardware needed to the terminal also

specified in Figure 3-1. Connect the Power/DGND leads LAST. Attach all leads with both the Electronics Power System and the Actuation Power Systems OFF. Terminal specifications are given as follows:

Table 3-1: Electronics Board/Hardware Integration Directions

Letter	Purpose	Input or Output?
A	Power	Input
B	DGND	Input
C	Reaction Wheel	Input
D	Sm Control Loop	Input
E	Electromagnet 2	Output
F	PWM Output	Output
G	Electromagnet 1	Output
H	Tach 2	Output
I	Tach 1	Output
J	IR Timing (Tied to K)	X
K	IR Timing (Tied to J)	X
L	Ultrasonic	Output
M	IR	Output
N	Ultrasonic 3	Input
O	IR 1	Input
P	Ultrasonic 2	Input
Q	IR2	Input
R	Ultrasonic 1	Input
S	IR 3	Input
T	Serial Port TT8-TT8 Comm.	I/O
U	Serial Port for Code Loading	Input
V	Serial Port TT8-TT8 Comm.	I/O
W	Serial Port for Code Loading	Input
X	Metrology IRQ3/MCLR (must be tied together for code loading)	
Y	Avionics IRQ3/MCLR (must be tied together for code loading)	
Z	Actuator Stop	Output
AA	Rate Gyro	Output

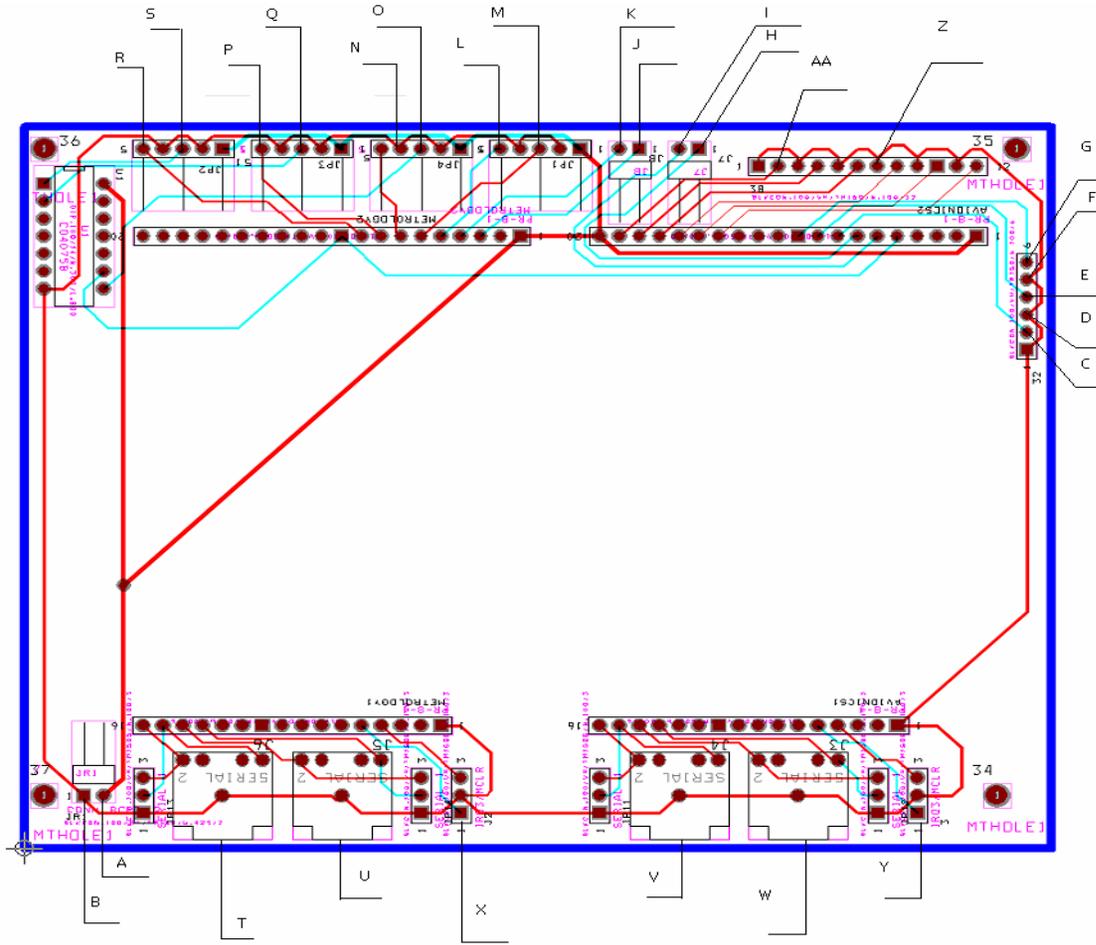


Figure 3-1:

Figure 3-1: Electronics Board/Hardware Integration Directions

3.4 Electronics Power (TS)

The power for all the electronics hardware is wired through the voltage regulator (VR) board. All connections to the VR board are made through single screw terminals. The connection is made by inserting one end of a wire into the terminal and turning the top screw tight. The two terminals at the top of the board connect to the AA-battery pack. One connects to the positive voltage terminal of the batteries, and the other connects to the negative. They are appropriately labeled. The negative terminal also serves as the common ground for the entire power system.

The VR board contains one +5V and one +12V regulator. Each regulator connects to a strip of positive and ground terminals. The 5V regulator has fourteen positive and ground terminals, while the 12V regulator has eight. More terminals can be added to either side as needed.

Each hardware component requires one connection to a 5V or 12V terminal and a second connection to a ground terminal. There are twelve hardware components that require a 5V connection:

- 2 EM power boards
- 1 RW power board
- 1 Tachometer
- 2 TT8 computers
- 1 TT8 a/d converter
- 1 DR2000
- 1 IR receiver
- 1 IR transmitter
- 1 Ultra-sound receiver
- 1 Ultra-sound transmitter

There are at least four hardware components that require a 12V connection:

- 2 EM power boards
- 1 RW power board
- 1 Gyro
- 1-3 power board fans (optional)

3.5 Electromagnets (TS)

The wiring for the electromagnets is through the two Electromagnet (EM) boards. There is one EM board for each electromagnet. At the top of each EM board, there are six screw terminals, each appropriately labeled. Two of the terminals connect to 5V and ground from the VR board, and two connect to 12V and ground. The fifth terminal connects to the signal wire from the on/off switch. The switch also requires a connection to ground, so it must share one of the two ground terminals. The sixth terminal connects to the signal wire from the Tattletale computer. The TT8 also requires a connection to ground, so it too must share one of the two ground terminals.

The wiring that carries the current between the batteries and the electromagnet is located on the underside of the EM board. Each EM board has three groups of MOSFETs, and the wiring for each group is identical. For each group, there are two pairs of red and black 12-gauge wires, each appropriately labeled. One pair connects to the positive and negative terminals of a D-cell battery pack. The other pair connects to the beginning and end of the electromagnet coil. All connections use Anderson brand connectors.

3.6 Reaction Wheel (TS)

The Reaction Wheel (RW) board is identical to the EM board, except that the RW board has only one group of MOSFETs. The six terminals at the top of the board have the same connections as the EM boards. On the underside of the board, one of the pairs of wires connects to a D-cell battery pack, while the other pair connects to the positive and negative wires of the reaction wheel motor. All connections use Anderson brand connectors.

4 Cryogenics (MW)

The electromagnet wire only exhibits superconductor properties when kept below 110 K. Therefore, it is important that it is kept encased in liquid nitrogen throughout the duration of the test. The cryogenics system is comprised of the liquid nitrogen tank, outer coil container, and inner coil container. The bottom of the tank has four brass 1.5” drain pipes that connect to the inner and outer coils, each with two drain pipes. Figure 1 shows the overall design of the cryogenic containment system, and Figure 2 shows the pipe clamp connections between the tank and coil assemblies.

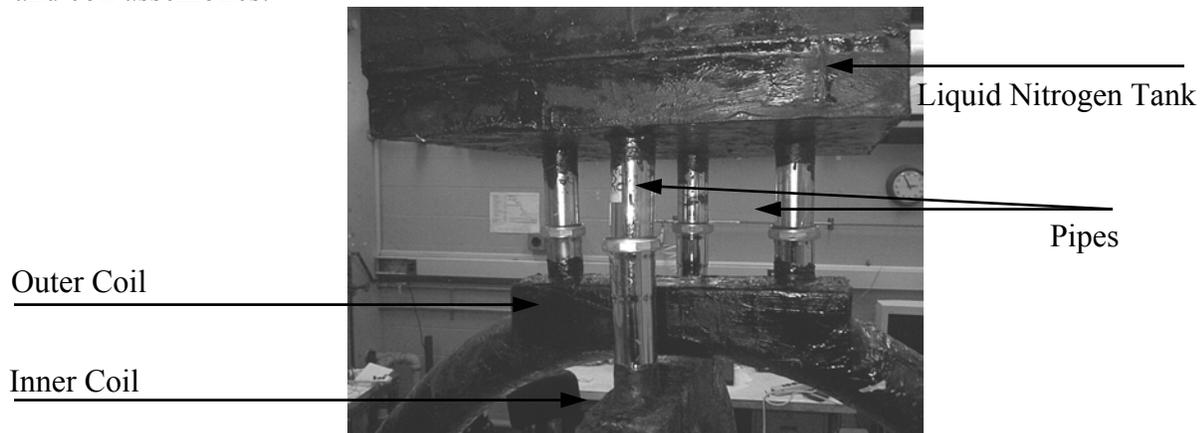


Figure 4-1: Cryogenic System Overview

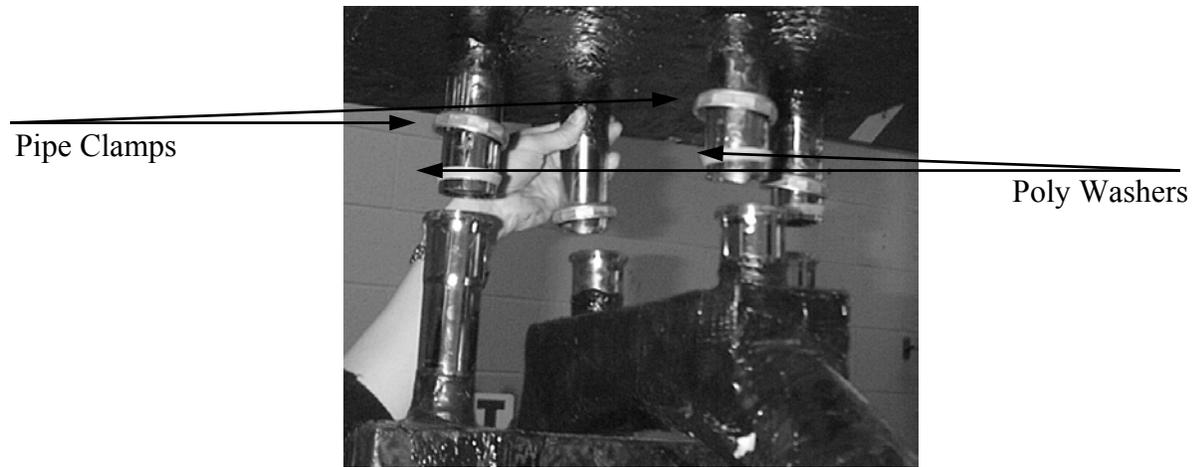


Figure 4-2: Tank-Coil Interface

4.1 Tank Removal and Assembly

The tank may be removed from the coils by unscrewing the pipe clamps. The tanks are not interchangeable between vehicles and only fit on the coils in one direction. If the pipes are not aligned, rotate the tank until they fit. It is important to have 1.5" Poly washers on each of the pipes to prevent leaking at the connections. Rubber washers will crack and leak.

4.2 Liquid Nitrogen

To fill the coil containers and tank, remove the tank lid keeping in mind that there may be metrology hardware attached. Fill the vehicle through the tank with liquid nitrogen either by pouring it from a container or by directly piping it to the vehicle from the liquid nitrogen tank. It is normal for the vehicle to make cracking noises as it contracts. Once the tank is full, the lid should be secured before operation.

4.3 Test Duration

The coils stop superconducting once the liquid nitrogen level falls below 75% of the coil containers. The tank holds enough liquid nitrogen to fully replenish both the inner and outer coil completely once. With the tank full, the liquid nitrogen supply should allow for approximately 20 minutes of operation before the coils stop superconducting.

4.4 Other

- Leaks will occur due to the thermal cycling that the containers are subjected to. They may be patched with epoxy and fiberglass cloth.
- If the coil containers are filled separately, the inner coil must be filled before the outer coil is filled. The outer coil should never be filled independently or damage to the inner coil may occur due to contraction.
- Once filled with liquid nitrogen, the coil containers become extremely cold. If the vehicle needs to be touched while it is filled, it may be necessary to do so with gloves.

- Fill the tank carefully and slowly. The liquid nitrogen often reacts violently to the room temperature container.
- Frost forms on the tank, pipes, and containers. This may interfere with air carriage operation if the frost or condensation falls on the glass. Additionally, the electronics must be shielded from the water as the frost melts and drips.

5 Test Operations Control and Management (ESS)

5.1 Graphical User Interface

The GUI provides real-time test monitoring and data logging in support of EMFFORCE test operations.

5.1.1 Settings and Controls

These controls are available to the user from the LabView front panel

5.1.1.1 Time Sample

This variable sets the duration of the sample window during which the serial port will gather data from the Comm Board. It should be set to at least two packet durations in order to maximize the probability of capturing at least one complete packet. The duration of a packet is approximately 500 ms because of the interrupt timing in the operating system.

5.1.1.2 Header Tag

The header tag is currently set to “66” A two byte header sufficiently reduces the probability of misidentification of data as a header. This header is hard-coded into the avionics software, and should only be changed for a good reason. Changing the length of the header would require the resizing of the DR2000 packet length as well.

5.1.1.3 Data File

This control specifies the location of the telemetry file. A tab-delimited spreadsheet row will be appended to this file on each run though the loop. The file should be of type *.txt

5.1.1.4 Bytes to Read

This control sets the number of bytes to read after the header tag. Notice that this is twice the number of words to read *after the header tag*. This needs to be matched to twice the number of integers in the telemetry packet from the vehicle, and is currently set to 20 bytes in order to capture the 10-integer telemetry packet.

5.1.1.5 Default Settings:

- Resource name: ASRL1::INSTR
- Action: Read

- Baud rate: 115200
- Go: On
- Skip Wait: On

5.1.2 Displays

5.1.2.1 Graphs

Data from the output array are plotted in the charts to the right of the GUI. The variable to be plotted in each chart is determined by the “index” argument on the top of the graph. This can even be changed while the GUI is running.

5.1.2.2 Serial Read

The Serial Read display prints the truncated character string that is extracted by the GUI. Ideally, it should print a very similar string each time, with the seconds’ byte incrementing. Observing patterns in and length of the nonsensical ascii characters may indicate problems with receiving full packets from the communications system, or from other problems farther up the data stream. These bytes are stored to the default string file.

5.1.2.3 Real-Time Data Monitoring

By observing the real-time data the operator can diagnose several problems that may arise during testing, such as sensor drift or failure to update the MSA prior to control execution.

5.2 Safety

5.2.1 Shut-off switch

The test coordinator must always ensure that the vehicle is under at all times. During Test Phase I, the most common departures occurred when the PWM signal on the reaction wheel failed to 0% or 100%. This results in an uncontrolled spin that must be stopped by breaking the circuit to the Reaction Wheel using the Red kill switch. Sufficient test personnel must surround the vehicle so it can be shut down if necessary.

5.2.2 Test Area Border Tape

Secure the edges of the glass with two layers of masking tape. This will be sufficiently thick to prevent the air carriage from floating off the edge and onto the floor.

6 Actuation and Structures System Troubleshooting

6.1 Electromagnets (WF)

The electromagnets are contained within the two large black toroids positioned vertically, perpendicular to each other, at the center of the vehicle. In the event that the electromagnets fail to supply an electromagnetic force, as demonstrated through the use of a gauss meter or by holding an object of ferromagnetic material near the electromagnets and observing the reaction, the following steps should be taken to determine the root cause of the electromagnet’s failure.

6.1.1 LN2 supply level

The black Styrofoam toroids containing the electromagnets must be filled with liquid nitrogen for the superconducting wire to properly super conduct. If the electromagnets fail to perform as desired and there is no liquid nitrogen in the toroids, fill them with liquid nitrogen and again check the performance of the electromagnets.

6.1.2 Battery connections

The electromagnets are powered by a series of D-cell batteries run through power boards, which regulate the current flowing through the electromagnets. For the electromagnets to work properly the batteries must be fully charged and all power connections must be correctly made, furthermore the current controllers on the power boards must be outputting the appropriate current. For details on troubleshooting the power boards see section 8.1.1 below.

6.1.3 Coil shorts

If neither of the above procedures result in the successful operation of the electromagnets, use a Ohm meter to verify that the electromagnetic coils have not shorted. In the event that the electromagnetic coils have shorted, (this occurs when the clamps attached to the rings of superconducting material come in contact with each other and short) try violently shaking the toroid of the affected electromagnet. In the event that violence fails, you will be forced to operate on the toroids. Find a Dremel and carefully remove a small section of the Styrofoam toroid. NOTE: You will have to reattach this section when finished so be careful not to remove anymore than necessary. Using visual inspection of the now exposed superconducting coils, ensure that none of the connections are shorting. When all shorts have been fixed reattach the removed Styrofoam using fiberglass and epoxy. *See section on containment damage for details on patching the containers using fiberglass and epoxy*

NOTE: In the event that you cannot repair the shorts with a surgical operation, it is necessary to destroy the entire toroid to remove the superconducting wire and remake the toroid/superconducting wire assembly. This process is detailed in Appendix C, and is very costly and time consuming.

6.2 Reaction wheel (WF)

The Reaction Wheel Assembly (RWA) consists of black urethane disk mounted on top of small electric motor. The RWA is located in center of the vehicle mounted to the toroid rings with an aluminum cross brace.

6.2.1 Mounting

In the event that the aluminum mount for the reaction wheel breaks, it will be necessary to manufacture a new one. See Appendix H for details on how to assemble a new RWA mount.

When attaching the mount to the vehicle's two toroids it is necessary to ensure that the RWA is level. If the wheel is not level, place a level on top of the reaction wheel and adjust the screws, which connect the mount to the vehicle's toroids until the RWA is level in all directions.

6.2.2 Deformation

The reaction wheel is designed to operate below 7,000 RPM above 7,000 RPM the wheel will undergo permanent deformation. If the wheel undergoes over speed deformation, or damage of any other kind it cannot be repaired, it must be replaced with a new wheel.

6.2.3 Balance

The reaction wheels come pre-balanced. If they are not balanced there is nothing that can be done about. If they do not mount snugly to the shaft of the motor this may cause unbalanced behavior. This can be fixed by applying white masking tape to the shaft of the motor in successive layers until the wheel sits snugly around the shaft.

6.2.4 Power connections

Similar to the electromagnets, the RWA is powered by D-cells run through a power board. The batteries must be charged and connected for the RWA to work properly. To troubleshoot the operation of the power boards refer to section 8.1.1 below.

6.3 Packaging (WF)

6.3.1 Containment damage: Rings-to-tank interface

In the event that liquid nitrogen leaks from the toroids-to-tank interface check that the pipe fittings have been correctly attached and tightened. If the leak occurs between the pipes and Styrofoam add more epoxy and fiberglass to the joint and allow to cure.

6.3.2 Containment damage: Foam/epoxy structural integrity

If a leak occurs in the cryogenic containment system, small leaks may be patched with epoxy. When a leak is discovered, it should be marked, and the containment system should be emptied of liquid nitrogen and be allowed to return to room temperature before patching. The epoxy used for the containment system is Emerson & Cuming STYCAST 2850FT with Catalyst 23LV. The ratio of catalyst (23LV) to epoxy (STYCAST) is 17.5 : 100. To measure these quantities, syringes may be used for more accurate measurements. The opening of the syringe used for the epoxy may have to be widened since the epoxy is viscous. After the correct amounts of catalyst and epoxy have been measured, they must be stirred thoroughly until the mixture is homogenous. The mixture should be less viscous than the epoxy base alone and has a working time of approximately one hour before it becomes too viscous to use. The epoxy can then be applied liberally by brush directly onto the containment system where the leak is located. During the twenty-four hour cure period, the containment system should not be filled.

If a leak is larger, it may be patched using fiberglass cloth and epoxy. In this case, prepare the epoxy as outlined previously, and cut a piece of fiberglass cloth large enough to cover the leak area. Apply the epoxy to the containment system and lay the fiberglass over the epoxy. A second layer of epoxy should be applied over the fiberglass. The epoxy will still require twenty-four hours to cure during which the containment system should not be filled.

6.3.3 Brace failure

In the event that the braces suffer a catastrophic structural failure, consider the possibility that they may need to be redesigned and build new braces.

If the braces fail to keep the toroids from realigning, build and insert new and or extra braces.

6.3.4 Velcro failure

In the event that the Velcro attaching the various components to the structure fails to adhere properly, first ensure that you are attempting to attach a male to a female piece of Velcro and not using two Velcro pieces of the same gender. Second, ensure the Velcro pieces are clean as dirty Velcro pieces do not stick well. If the Velcro still will not adhere properly try replacing it with fresh Velcro. If some how Velcro just does not seem to be the solution get rid of the Velcro and use tape, the blue masking tape variety seems to work best. Finally, if you found it necessary to refer to the manual to troubleshoot a problem with the Velcro it is quite possible that the problem has nothing to do with the effectiveness of the Velcro.

6.4 Air carriage (AS)

6.4.1 Floatation problems

Flotation problems are indicated by the resistance of one or more pucks to motion along the flat floor as induced by the actuators or by outside force. There can be several causes for this, and therefore, several mitigations.

6.4.2 Puck supply line leaks

First, check the supply lines for leaks, especially around the fittings. Typically, a leak may be fixed by removing the offending fitting, cleaning it of old Teflon tape, rewrapping it with Teflon tape, and reinstalling it. Make sure when wrapping with Teflon tape that the tape is wrapped clockwise over the top of the fitting as the threaded end points towards you to prevent the tape from bunching up.

If the leak still exists, try removing the tube from the fitting by pressing down on the black insert and gently pulling on the tube. Next, snip off the end of the tube that is held by the fitting and insert the fresh end into the fitting.

If there are still leaks present, the leaking fitting must be replaced. The leaky fitting is unusable and should be disposed of.

6.4.3 Tank fill level

The tank may be empty. Check for dry ice chunks in the tank by shaking the tank and listening for rattling from inside. If there is ice inside, you must wait for the bottle to warm up and then empty the tank before refilling. A standard empty tank weighs approximately 710g, while a modified tank with on/off valve weighs approximately (850g) when empty.

To refill tanks, chill tanks in the freezer (located in the SPHERES lab) overnight. When cold, connect the bottle to the large siphon-fill CO₂ tank in the SPHERES lab. Open any on/off valve on the tank and screw the regulator completely down. Open the relief valve on the large tank slowly to empty the small tank completely. Close the relief valve firmly. Set the small tank on the scale and tare it. Then slowly open the fill valve on the large tank. Fill the small tank to approximately 460g. Be careful – the siphon tank fills quickly. When full, close the fill valve firmly. If there is an on/off valve on the tank, close it. Unscrew the regulator until gas hisses out and a half turn past that point. Slowly open the relief valve to vent the gas in the line. After this is done, the tank may be disconnected and is ready for use. The tank may be used at room temperature.

If the air supply ended earlier than anticipated and dry ice was discovered inside the tank, make sure that the water bath is at a warmer temperature for the next test.

6.4.4 Clean table/pucks

The gap height upon which the vehicles float is very small, and any obstruction may cause interference to the flotation abilities of the carriage. Make sure that the flat floor is clean. Vacuum the floor for large particles, then wipe clean with surface cleaner and a soft, lint-free cloth.

Check the bottom surfaces of the pucks for dirt and scratches. Remove the pucks from the carriage and clean with alcohol. After cleaning, run the pad of your finger over the bottom surface of the puck. If you can feel any bumps caused by burrs or gouges, the puck must be polished. Take it to the emery boards in the 35-1xx machine shop for polishing. Swipe the puck over the coarse board in a figure-eight pattern for about 30 seconds. Repeat for the fine board. Check bottom surface with the pad of your finger and repeat if necessary. Clean with alcohol to remove dust before reinstalling in the carriage.

6.4.5 Tank O-ring rupture

The o-ring around the very top of the tank's valve is essential for providing sealed air supply to the carriage. The o-ring must be visually inspected for tears or for excessive stretching. Replacement o-rings are stored with the air carriage supplies, and are available through paintball suppliers. (AS)

6.4.6 Tank Overfill

Tanks should not be overfilled. If the fill mass exceeds 490g, some of the gas should be bled off using the pin valve actuator fitting in the SPHERES lab.

6.4.7 Tank burst disk

The tank valves are equipped with burst disks designed to blow and relieve the pressure inside the tank before it becomes dangerous to its surroundings. In the event that the burst disk is required, the tank must not be used again until the burst disk is replaced. Replacement burst disks are available through paintball suppliers.

6.4.8 Regulator inconsistency/freezing

The diaphragm regulators in use on the vehicle are affected by temperature. The tank must be in a water bath to stabilize the temperature change. Be sure the regulator pressure is initially set sufficiently high so that a slight deviation will not cause the carriage to settle. If the carriage settles because of insufficient pressure, the pressure must be manually reset to a high pressure adequate to push the system off the floor. Such a manual adjustment could disturb a test in progress, so consult the operations team for appropriate action.

7 Power, and Avionics Troubleshooting

7.1 Power (TS)

7.1.1 Power boards

The power boards are used to control current to the electromagnets and the reaction wheel. Follow these steps if there seems to be a problem with supplying power to the vehicles.

1. Disable Switch. See if the disable switch is turned off. If so, switch it on.
2. Batteries. Check to make sure the batteries are fresh. Replace all old batteries with newly charged batteries. It is good practice to replace all the batteries together, rather than mixing old batteries with fresh batteries.
3. Wiring. Make sure all the 12-gauge wires are hooked up properly to the batteries and the magnet or reaction wheel. All the wires should be labeled properly, but refer to the schematics if there is further doubt.
4. If there is a burning smell and/or smoke, check to make sure that none of the MOSFETS and heat sinks are bent over and touching each other. This creates a short across the MOSFETS and causes the batteries to rapidly discharge and push over 100 amps through the board almost instantaneously. If the MOSFETS did short together, carefully bend them back straight. (Caution: bending them too much or too often may cause them to eventually break off). After that, if they are still not working properly, the affected MOSFETS may need to be replaced.
5. A burning smell and/or smoke may also be caused by an electrical short in the wires on the underside of the board. Check to make sure none of the thick wires are touching each other. Check to make sure all the solder joints are solid and that two wires that should be separate haven't been accidentally joined together.
6. Finally, the MOSFETS may burn out if the batteries are connected backwards. Check to make sure the positive end of the batteries is attached to the correct positive power board wire. (And likewise with the negative). Hooking up the batteries backwards causes the current to run backwards through the MOSFETS, which eventually burns them out.

7. If the problem does not seem to be with the MOSFETS or 12-gauge wiring, the problem may be in the circuitry. First check for any bad solder connections on any of the circuitry components. Each board has been tested before being used on the vehicle, so theoretically everything should be wired together correctly.
8. One of the individual components of the circuitry may be burned out. By breaking some of the connections, it should be possible to test each component individually to isolate which chip needs to be replaced. Replacing chips is difficult and should be avoided unless absolutely necessary.
9. It would also be a good idea to make sure the power board is connected to all the proper inputs: +5V, +12V, Ground, Input signal, and Disable switch.

7.1.2 Voltage regulator boards

The voltage regular boards provide +5V and +12V to all the electronics equipment onboard the vehicle, including the electromagnet and reaction wheel power boards. Follow these steps if there seems to be a problem with the board.

First check to make sure the batteries are fresh. Replace all old batteries with newly charged batteries. It is good practice to replace all the batteries together, rather than mixing old batteries with fresh batteries.

Check for any bad solder connections on any of the components. Each board has been tested before being used on the vehicle, so theoretically everything should be wired together correctly.

One of the voltage regulators may be burned out. It should be possible to test each regulator individually to isolate which one needs to be replaced. Replacing voltage regulators is difficult and should be avoided unless absolutely necessary.

7.1.3 Batteries

The EMFFORCE vehicles use AA and D-cell rechargeable Nickel Metal Hydride (NiMH) batteries. At the beginning of each test, all batteries should be replaced with freshly charged batteries. The AA batteries are fully charged when the charger light turns to green. For the D-cells, the charger light turns green after 7 hours of charging, regardless of the status of the batteries. Because of the unusually high capacity of the 9000 mAh D-cells, each battery may need up to 3 seven-hour charge cycles before it is fully charged.

The batteries should be recharged when their voltage drops below 0.8V. Draining them past this point may result in permanent damage to the batteries, although recent improvements in battery technology has helped to minimize the chances of damage due to this. All the batteries should last through at least 500 charge/discharge cycles.

When working with the D-cell batteries, special precaution should be taken while loading the batteries into their metal holders. Because the holder is made of steel, it is easy to create an electrical short which will cause sparking and the batteries to heat up. It is not a serious problem

if this occurs (no permanent damage should be incurred); however, caution should be used when handling the batteries. Also, because the optical table has a metal surface, it is also possible to create an electrical short if the battery holders are placed directly on the table. To prevent this, try to keep the batteries and holders on the glass at all times.

7.2 DR2000 Communications boards (JEU)

A RFM DR2000 transceiver board is shown below in **Error! Reference source not found.** (the antenna shown is not the same as the one used by the EMFFORCE system):



Figure 7-1: DR200 Transceiver Board (RFM)

This section is devoted to addressing the trouble shooting issues that have come up during the development of the EMFFORCE system. For a schematic of the DR2000 board, please refer to the RFM DR2000 Manual included on the EMFFORCE CD.

7.2.1 Should the DR2000 LEDs flash like that?

It depends. The LEDs flash differently under different circumstances. Figure 7-2 depicts the board layout of the DR2000. LED's 1, 2 and 3 can be found near the top of the schematic.

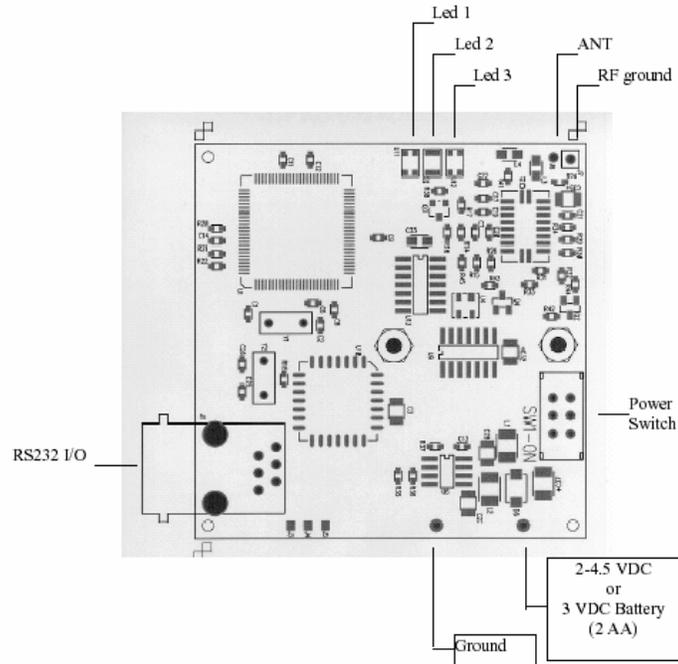


Figure 7-2: DR2000 Board Layout (RFM)

Here is a simple algorithm for determining the state of the communications system based on the behavior of the LEDs:

```

if ((LED 1 = Green Flashing ~ 0.5 Hz) & (LED 2 = off) & (LED 3 = off))
    Then "System Standing By";

else if ((LED 1 = Red Flashing ~ 0.5 Hz) & (LED 2 = off) & (LED 3 = off))
    Then "Range Test is ON" or "Board is transmitting";

else if ((LED 1 = Green Flashing ~ 0.5 Hz) & (LED 2 = on) & (LED 3 = Green))
    Then "Board received good data";

else if ((LED 1 = Green Flashing ~ 0.5 Hz) & (LED 2 = on) & (LED 3 = Red))
    Then "Board received bad data";

else if ((LED 1 = Green or Red Flashing ~ 0.2 Hz) & (LED 2 = off) & (LED 3 = off))
    Then "Command Error";

```

Note: The indicator for "good data" occurs when FC1 agrees with FC2 (please refer to Error Detection and Correction Routines for a brief discussion of FC's). The indicator for "bad data" occurs when FC1 and FC2 do not agree.

7.2.2 I keep receiving bad packets. What could be going wrong?

Several things could be happening. Here is a checklist for diagnosing the problem:

1. Is your power source low?

If the DR2000 does not receive enough voltage, it may read the packets incorrectly or not at all. This effect was found to occur when the batteries were nearly dead. The exact location of this effect on the power curve has not yet been determined.

2. Is the antenna connected properly?

If the antenna does not touch the proper lead on the DR2000 or if there is a short in the connection, the DR2000 may respond by declaring a bad packet.

3. Is the proper Packet Size stored in the DR2000 flash memory?

If a change has been made in the packet structure, but the change has not been reflected in the DR2000 flash memory, the DR2000 may not interpret the incoming bytes correctly.

4. Is the proper From Address stored in the DR2000 flash memory?

If a DR2000 thinks it is connected to Vehicle 1, but it is connected to Vehicle 2, then a bad packet message could occur if Vehicle 2 attempts to transmit as Vehicle 2.

5. Is the proper To Address stored in the DR2000 flash memory?

Setting the To Address to broadcast ('0x00') should not result in a bad packet.

However, if the receiving DR2000 thinks it is Vehicle 1 and the transmitting DR2000 is attempting to transmit to Vehicle 2 only (i.e., it is no longer broadcasting), then the receiving DR2000 may display a bad packet. Of course, if you have a network of nodes, and you are transmitting to one in particular, all of the other nodes will flash as though they have received bad packets. In this case, it means that the packet wasn't meant for them.

6. Are there any external noise sources operating near the frequency range used by the DR2000s?

Other devices operating near the DR2000 frequency range may interfere with the packet transmission and result in a bad packet via packet collision.

7. Is the packet number at least one count different between packets (e.g., the packet numbers increment and repeat like: 1 2 1 2 or 1 2 3 4 5)?

If the packet number is not at least one count different between the packets, then the ARQ (Automatic Repeat Request) function cannot work. This may potentially result in a bad packet signal.

8. Is the proper data length used in the software?

The data length used in the software should be:

Number of data bytes + 5 (in HEX)

9. Is the RS232 baud rate at 115200?

The communications board integrates with the RS232 serial line at a baud rate of 115200. To ensure against lost packets, packet collisions, etc, it is necessary to set the RS232 baud rate to 115200.

10. Is there a small delay between the transmission of each byte?

Without a small delay between the transmission of each byte, there are errors with the DR2000 buffer. When the buffer overflows, bytes are lost and the receiving DR2000 correctly interprets this as a bad packet.

7.2.3 We've changed the packet size and it doesn't work. Why not?

You've probably forgotten to propagate the changes to the packet size through the system. Every communications board needs to have the Packet Size value adjusted (in HEX) and the software needs to have the length value updated (number of data bytes + 5 in HEX). Also, the value for the packet size in the GUI will need to be updated.

7.2.4 We reset the DR2000s, but now we're getting bad packets. What happened?

If you have made any changes to the DR2000's via any of the DR2000 commands that do NOT store their values to the flash memory, you will need to redo the commands every time you reset.

7.3 Wiring (JEU)

7.3.1 How do we connect the TT8 to the DR2000?

In order to construct a replacement RS232 cable, you should use a QSPI serial device to connect to the DR2000 and a serial plug for the TT8. You will also need to find wiring and solder as necessary (depending on the connection device).

Table 7-1 describes the wiring assignments for the RS232. This information will be useful as a reference.

Table 7-1: Table of RS232 Connector Wiring Assignments (courtesy of the RFM DR2000 Manual)

RS232 Connector wiring:

DB9 Female	RG11-6 (Straight)	Signal
Pin1 & Pin 6	Blue	DCD
Pin2	Black	RX
Pin3	Red	TX
Pin4	N/C	
Pin5	White	Ground
Pin6	Yellow	DSR
Pin7	N/C	
Pin8	Green	CTS
Pin9	N/C	

7.3.2 Serial Plug

There are only three connections that we're interested in: Ground, TX (transmit) and RX (receive). To connect to the serial plug for the TT8, please refer to Figure 7-3. If you're using a spare DB-9 Serial Cable to make the connection, you will want to find the wires corresponding to Pin 3, Pin 4 and Pin 5.

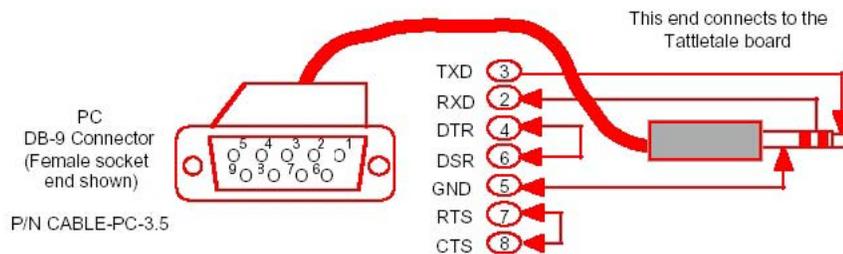


Figure 7-3: Serial Plug Diagram (courtesy of the TT8 Manual)

However, if you are using a standard serial plug (not a cable), then you will want to use the schematic in Figure 7-4 to determine where to connect the wires.

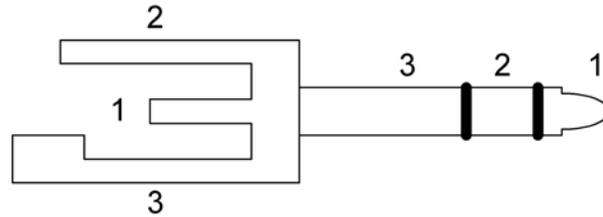


Figure 7-4: Schematic of Serial Plug

The Function Assignment Table (see Table 7-7-2) provides a reference for the color scheme used in the current RS232 cabling implementation in addition to correlating the function (TX, RX, Ground) and the assignment number (1, 2 or 3).

Table 7-7-2: Function Assignment Table

Function	Assignment	Our Wire Color
Transmit	1	White
Receive	2	Black
Ground	3	Green

7.3.3 QSPI Connector

The QSPI port on the DR2000 is circled in Figure 7-5. The RS232 connector (also known as a QSPI or Queued Serial Peripheral Interface) plugs into the QSPI serial port. A schematic of the connector is also shown in Figure 7-5 for reference when connecting the wires.

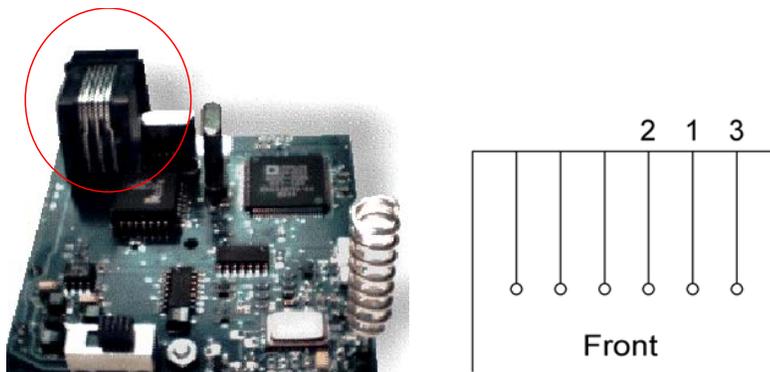


Figure 7-5: Identification of QSPI port on DR2000 (left) and Schematic of QSPI connector (right)