



***HCS01 THREE-AXES HELMHOLTZ COIL SYSTEM  
OPERATION AND MAINTENANCE  
MANUAL***

Mar 2021

MEDA DOC ID 00536 Rev B.

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# 1 INTRODUCTION

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This manual provides information and instructions for installing, operating, and maintaining the HCS01 Triaxial Helmholtz Coil System.

## 1.1 SYSTEM DESCRIPTION

The HCS01 is a three-axis Helmholtz coil system that can be used to apply precise and accurate magnetic fields in three orthogonal axes. The HCS01 consists of three 2-meter<sup>1</sup> square sets of Helmholtz coils (see Fig. 1-2) arranged to form three orthogonal axes and a rack assembly (see Fig. 1-3) which contains bipolar power supplies (BOP) and a CCM-3 coil control magnetometer.

A three-axis fluxgate sensor that is part of the CCM-3 coil control magnetometer is located in the central region of the coil assembly. In the closed loop configuration, the sensor, field control unit electronics, and BOPs form a negative feedback system which forces the field in the center of the coil system to approach zero, thereby automatically compensating for uniform ambient fields (e.g. Earth's field). In the open loop configuration, the field inside the coil assembly is not compensated for changes in the ambient field but does compensate for the nominal ambient field.

The BOPs, CCM-3 and the PC power cords are plugged into a single power distribution unit (PDU). One switch on the PDU is used to turn the HCS01 power on or off. Alternatively, an Uninterruptable Power Supply (UPS) can be used to protect the system in the event of brown outs or black outs.

A PC is connected to the CCM-3 and used to control the polarity and magnitude of the magnetic fields under the direction of the operator using Standard Commands for Programmable Instruments (SCPI) syntax. The features are summarized below:

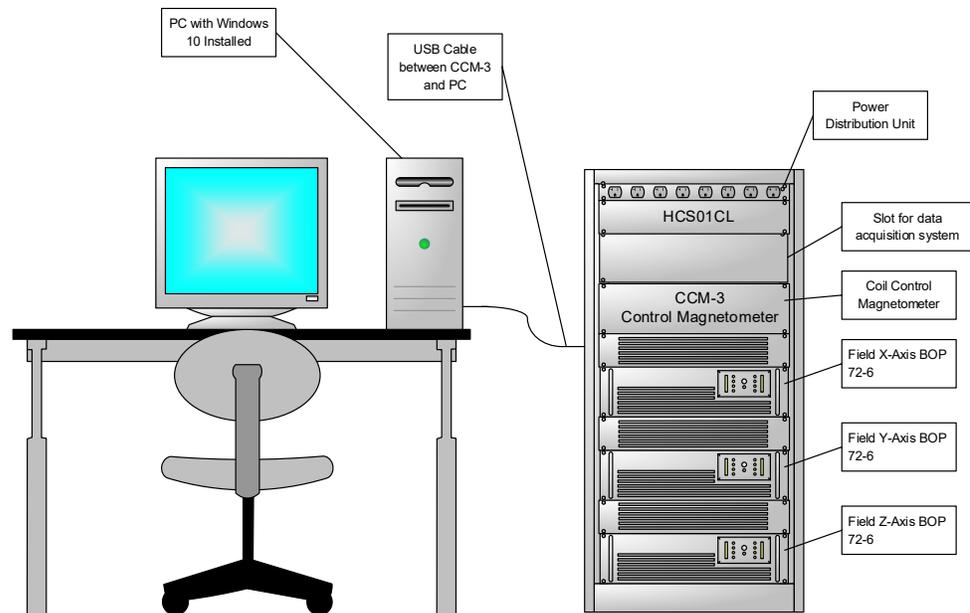
- USB serial port physical interface
- Uses the SCPI (Standard Commands for Programmable Instruments) syntax described in the SCPI Consortium standards.
- Interface includes commands for
  - Setting or getting the zero adjustment values
  - Setting or getting the magnetic field component values.
  - Setting or getting the calibration factors (protected command).
  - Loading and sequential executing a list of field vectors at a prescribed rate.

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1 This manual applies to the MEDA 3-meter and 4-meter coil systems .

- Generating period fields (Sine wave, Square wave, Ramp).
- Performing a self-test
- Identifying the instrument
- Compatible with LabView and MatLab
- No special software interface libraries required for designing custom test software.
- Can be controlled by a USB serial port from any operating system.

The following figures provide a general arrangement diagram for the system plus views of the coil and rack assemblies.



HCS01 RACK & PC GENERAL  
ARRANGEMENT DIAGRAM

*Figure 1-1 HCS01 general arrangement diagram.*

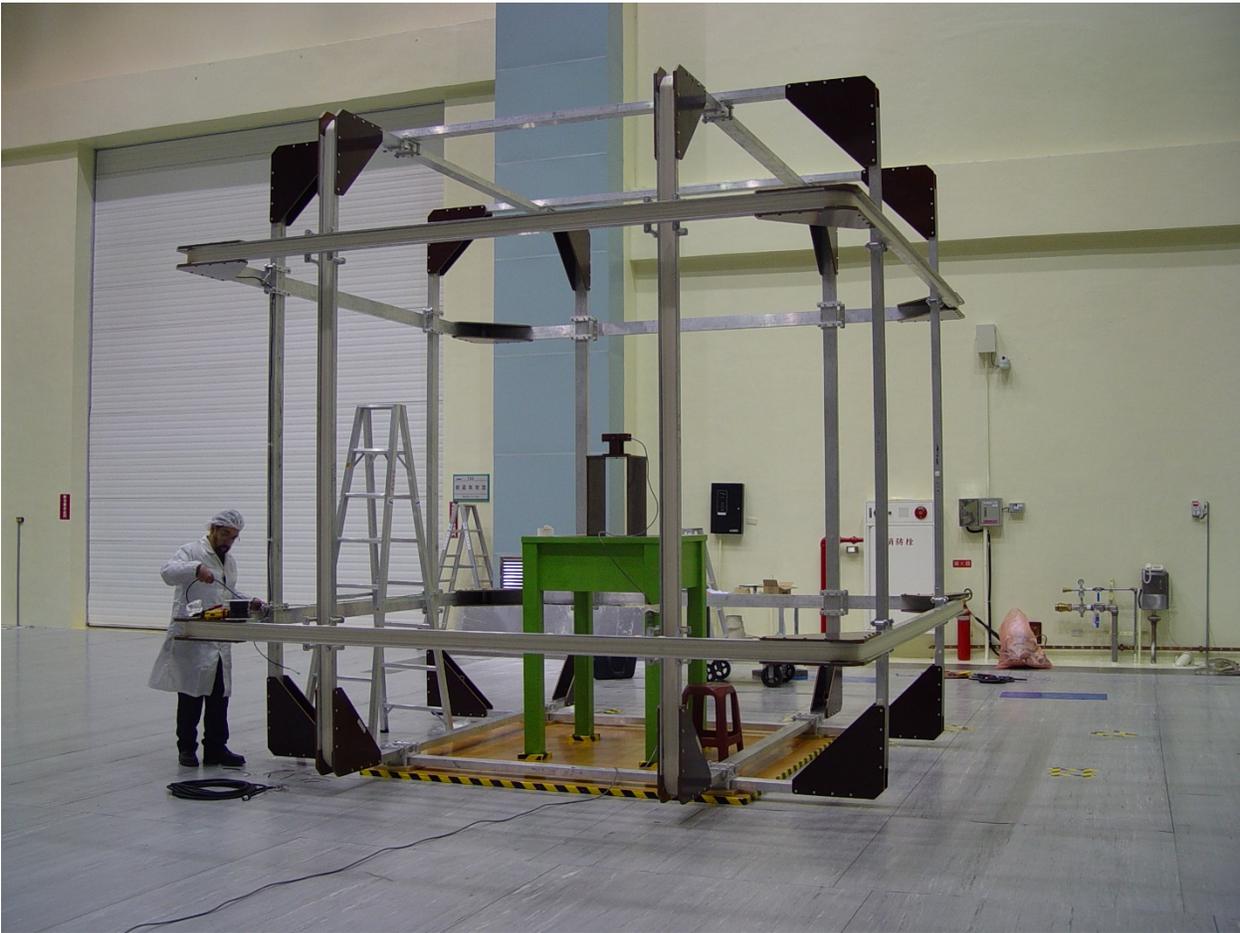
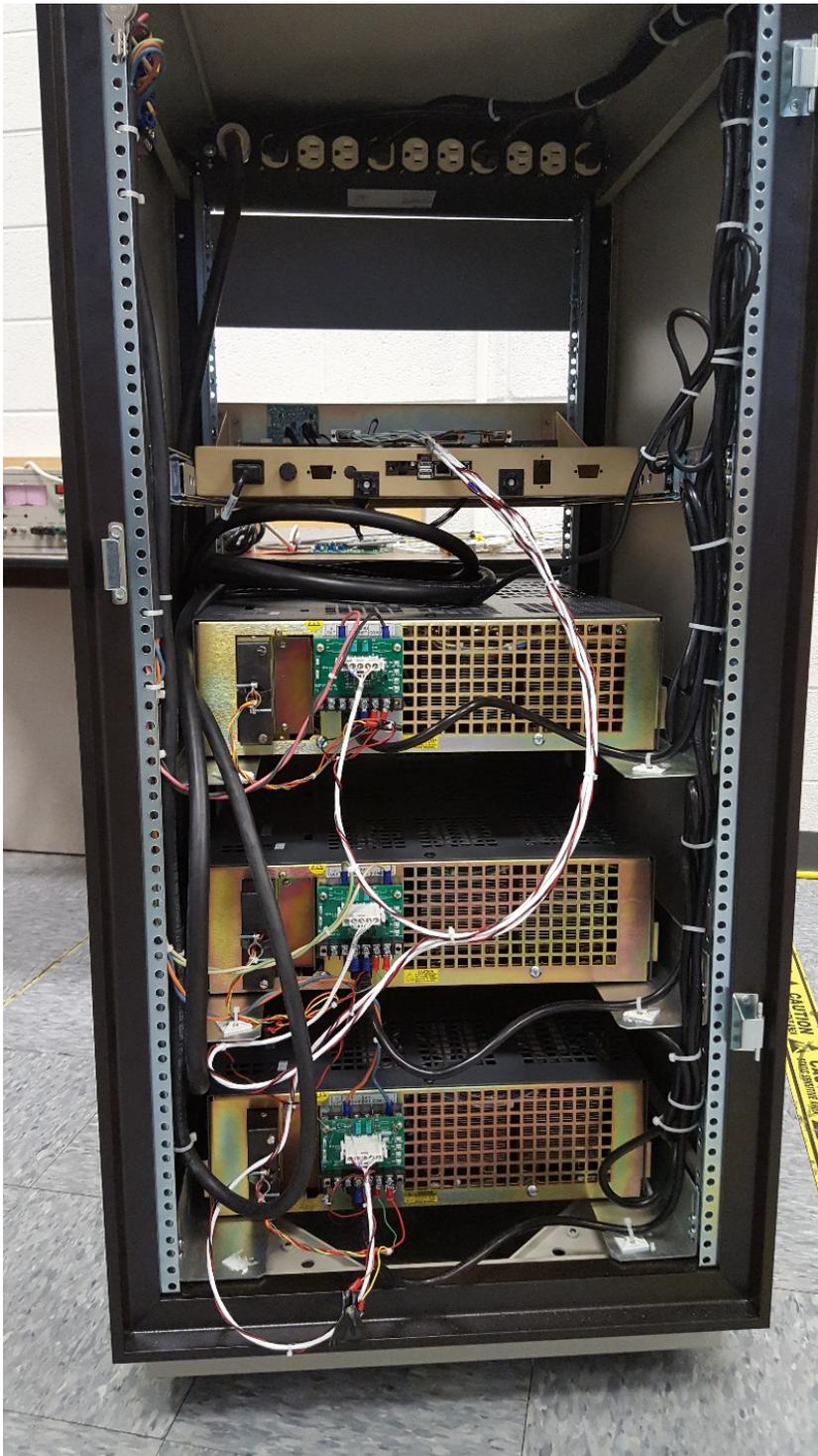


Figure 1-2 HCS01-4m coil assembly.



Figure 1-3 HCS01 Rack Assembly front view.



← PDU

← CCM3 Control  
Magnetometer

← X Axis BOP

← Y Axis BOP

← Z Axis BOP

Figure 1-4 HCS01 rack rear view

**1.2 SYSTEM SPECIFICATIONS (2-METER SYSTEM)**

|                                  |   |
|----------------------------------|---|
| <b>GENERATED FIELD</b>           |   |
| Range:                           | $\pm 200,000$ nT  |
| Resolution:                      | $\pm 10,000$ to $\pm 200,000$ nT Range: 0.4 nT<br>0 to $\pm 10,000$ nT Range: 0.02 nT               |
| Accuracy (Zero field corrected): |   |
| Initial @ 23°C                   | $\pm 0.05\%$ of setting   |
| Temperature Coefficient          | $\pm 10$ ppm/°C nominal   |
| <b>ZERO FIELD</b>                |   |
| Trim Range                       | $\pm 4000$ nT nominal   |
| Resolution                       | 1 nT nominal  |
| Stability                        |   |
| Temperature                      | $\pm 0.1$ nT/°C nominal   |
| Drift                            | $\pm 3$ nT over 8 hours at constant temperature   |
| <b>PHYSICAL CHARACTERISTICS</b>  |   |
| Overall coil size                | 160" x 160" x 162"  |
| Coil weight                      | Approximately 2000 lbs.   |
| Control unit size                | 22.06" W x 40.82" H x 26.40" D  |
| Control unit weight              | Approximately 350 lbs.  |
| <b>ENVIRONMENT</b>               |   |
| Operating temperature            | 0°C to 50°C   |
| Storage temperature              | -10°C to 70°C   |
| Relative humidity                | 10% to 90%  |
| <b>POWER REQUIREMENTS</b>        |   |
| Voltage                          | 115 VAC @ 50-65 Hz (an UPS can be provided to power the system from 220 VAC 50 Hz commercial power) |
| Current                          | 30 Amperes maximum (16 Amperes maximum at 220 VAC 50 Hz)  |
| FIELD UNIFORMITY                 | <0.03% of applied field within 50 cm diameter sphere at coil system center                          |
| <b>AXIS ORTHOGONALITY</b>        |   |
| Without Compensation             | $\leq 1.0$ degrees  |
| With Compensation                | $\leq 0.1$ degrees  |

## 2 INSTALLATION

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Although it is recommended that MEDA perform the initial on-site installation and calibration of the HCS01, the User can install and calibrate the system using instructions and software provided by MEDA. The following sections provide a description of how to install and calibrate the system.

### 2.1 UNPACKING AND INSPECTION

The HCS01 arrives at the site in several packages. The coil assembly and rack assembly were disassembled and placed into different packages. Reassembly of the system is discussed in future sections.

A list of the packages and their contents accompanies the shipment. The User should verify that each of the listed packages was received; unpack each item; and inspect each item for shipping damage before attempting to reassemble the system.

### 2.2 SITE REQUIRMENTS

The HCS01CL can generate very uniform, stable, and accurate magnetic fields in the central region of the coil assembly. External environmental conditions can cause suboptimal performance of the HCS01CL.

The floor upon which the coil assembly is mounted should be constructed of non-magnetic materials. If the floor is concrete and contains reinforcing rods then the coil assembly base should be raised at least ten (10) inches above the floor.

Field uniformity in the central region of the coil system will be affected by ambient magnetic field gradients. These gradients can be caused by ferromagnetic material in the vicinity of the coil assembly. The magnetic field gradient should be less than 20 nT per foot within a one-foot diameter sphere centered about the geometric center of the coil assembly.

The HCS01CL can compensate for uniform changes in the ambient field but not for gradient changes. The coil assembly should be located in a region where there is minimal movement of ferromagnetic objects such as automobiles, forklifts, steel doors, etc. No ferromagnetic objects should be located within 15 feet of the edge of the coil assembly. The coil assembly should be located at least fifty (50) feet from a parking lot, railroad right-of-way, or roadway.

It is highly recommended that the temperature of the facility, where the HCS01CL is located, be maintained between 22 and 24°C.

### 2.4 COIL ASSEMBLY

#### 2.4.1 Overview of Assembly Procedure

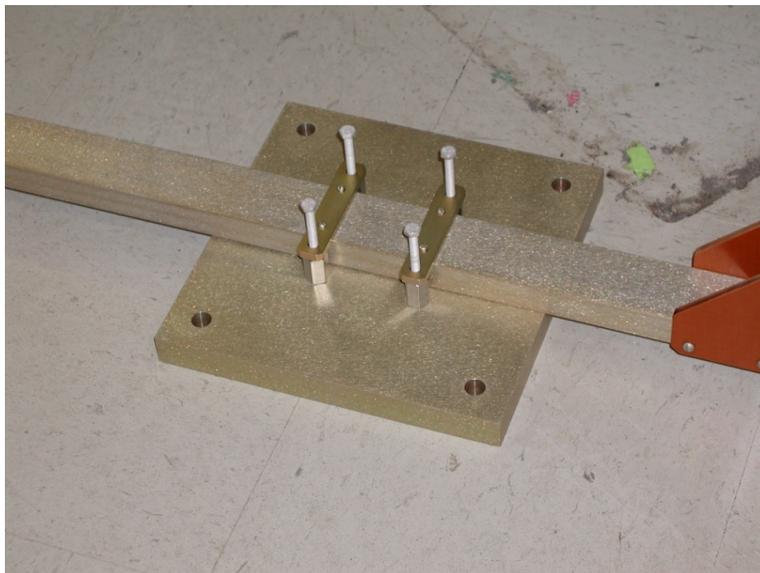
The following procedure is used for all of the coil assemblies that MEDA provides. The photos demonstrate the procedure for the 2-meter coil assembly. The 3-meter and 4-meter coil assembly procedure is basically the same but they usually require cranes or fork lifts to assist in moving and securing the coils.

Prior to beginning the assembly, the Z coils are placed on the floor, because it is much easier to lift them up into position from there than to bring them down from above the erected X and Y coil nest. In the HCS01 case the Z coils are placed on the floor of the pit



*Figure 2-1 Starting configuration with Z-axis coils on the floor*

The first step is to place the two X coils, which are the middle-sized coils, directly on the mounting pads. This results in two freestanding vertical coils as shown in Fig. 2-3.



*Figure 2-2 X-axis coil mounted to one of the pads.*



*Figure 2-3 X-axis coils in place.*

The next step is to insert the Y-axis coils, which are the smallest, inside the X coils, and fasten them to the mounting pads and to brackets that secure them to the X coils at the top.



*Figure 2-4 X and Y-axis coils in place.*

The next step is to place the upper of the Z-axis coils around the other coils, and join it to them at eight points with spacers and bolts. Then the lower Z coil is added. The result is the interlocked nest of six coils joined to themselves and to the mounting pads. See Fig. 2-5.



*Figure 2-5 X, Y and Z-axis coils fully assembled.*

Finally, the CCM-3 magnetometer sensor is installed in the coil assembly completing the coil system assembly. The sensor is mounted to a podium in the center of the coil assembly.

## **2.4.2 Preparation for Coil System Assembly**

The site for the installation needs to be chosen with regard to the guidelines given in the Site Requirements section. If a spacer frame is required to separate the coil system from magnetic material in the floor, it should be constructed and the coil system placed upon it. A square frame made from 2"x10" pine is suggested. Use nonmagnetic nails or screws to assemble it.

Also, attention is traditionally given to the orientation of this kind of system with respect to the magnetic field of the earth. Although this is not required with an automatic feedback system like the HCS01, it is probably a good idea to orient the system so that the positive X-axis points north and the positive Y-axis points east. These directions are marked on the coils and drawings. In this way the Y-axis is approximately aligned with the null plane of the Earth's field, which can be convenient for certain tests made with the coil control system in open loop mode.

### **2.4.2.1 Pre-positioning of Z-axis Coils**

Please refer to Fig. 2-1.

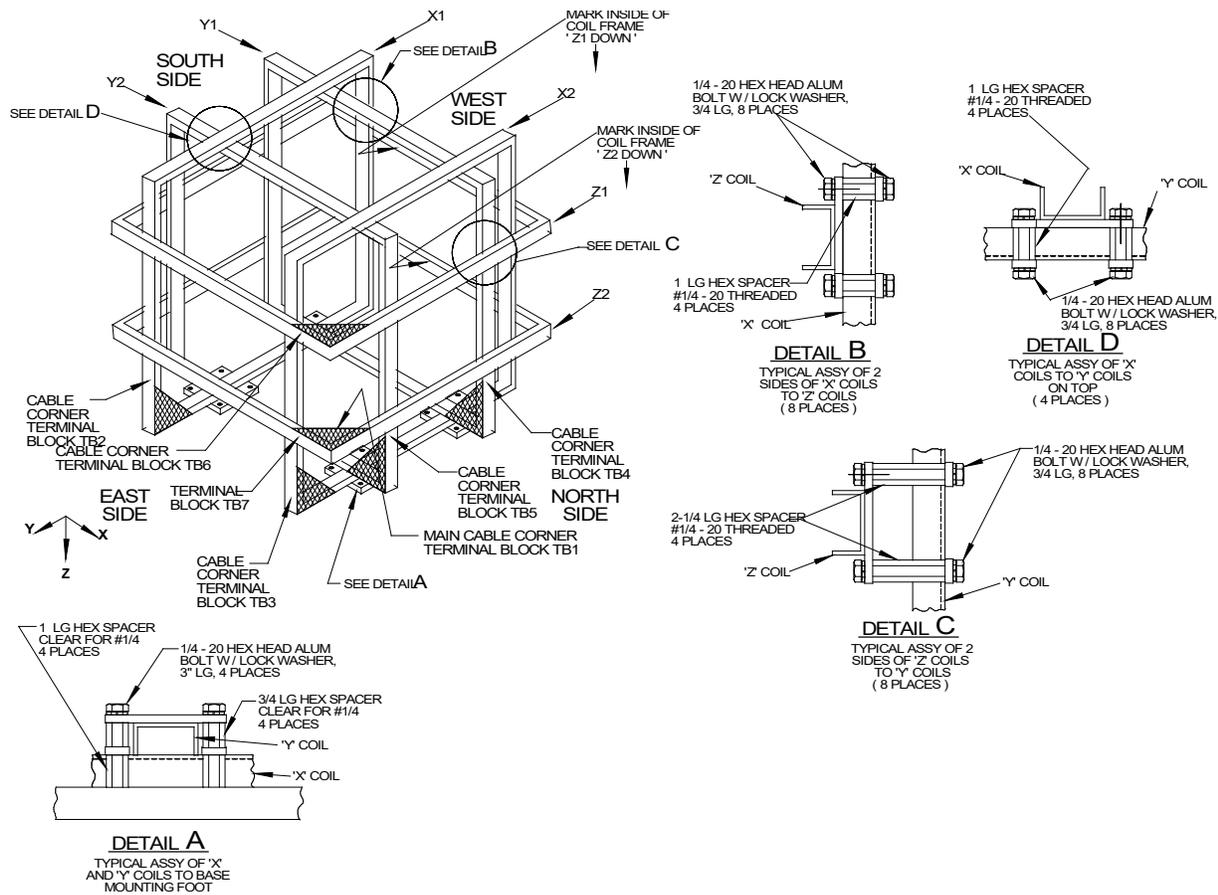


Figure 2-6 Final Assembly

1. Place the Z2 coil on the floor, orienting it so that the marked arrow points down and the side with the marking on it is adjacent to the west side of the frame, as shown in the drawing. The Main field cable corner marking is on the northeast corner.
2. Place the Z1 coil over the Z2 coil, orienting it the same way. The cable corner marking is on the northeast corner.
3. Place a footpad on the floor approximately at the intersection of the lines joining the vertical brackets attached to opposite sides of the Z-coils (four positions).

**2.4.2.2 Assembly of X-axis Coils**

Two people are required for the assembly of the coil system, although three will make the job easier. Please refer to Fig. 2-3. The drawing shows the northeast corner of the coil assembly to be nearest the viewer. This is the corner from which the electrical drive cable for the field coils will emerge.

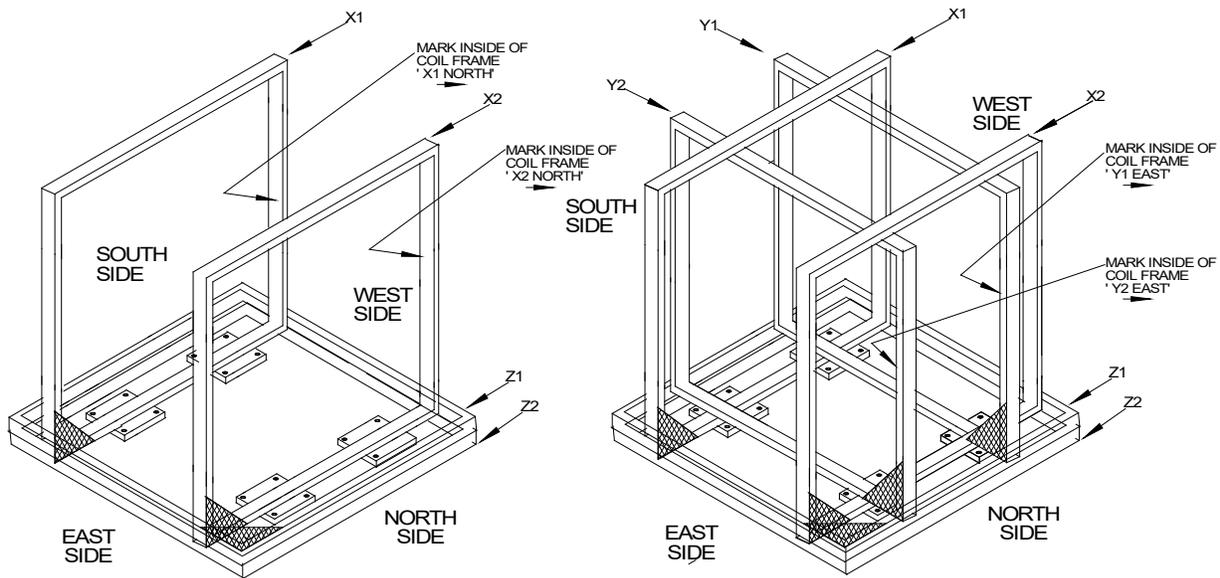


Figure 2-7 X-Axis and Y-Axis Assembly

1. Place the X1 coil with the marking upright and the marker arrow pointing as shown in Fig. 2-7. Make sure the coil is resting on the two footpads in line with it.
2. Repeat step 1 for the X2 coil.
3. Use an A-frame to hold the two coils upright and clamp a crossbar between the tops of the X coils while performing the Y-axis coil assembly.

#### 2.4.2.3 Assembly of Y-axis Coils

Please refer to Fig. 2-4.

1. Insert the Y1 coil inside the X coils and over the mounting pads on the west side. The coils fit together closely, requiring care in assembly to avoid marring the finish.
2. Carefully align the mounting pads with the brackets on the X1 and Y1 coils. Insert spacers and screws into mounting pads as shown in detail A of Fig. 2-6. Align carefully until aluminum screws can be turned by hand.
3. Repeat step 2 for the X2 and Y1 coils.
4. Repeat steps 1 through 3 for the Y2 coil.
5. At the top where the X and Y coils cross, install threaded spacers, 1/4-20 x 3/4" long hex screws and lock washers to the brackets as shown in detail D of Fig. 2-6.

This completes the assembly of the X coils to the Y coils.

#### **2.4.2.4 Assembly of Z-axis Coils**

Please refer to Fig. 2-4.

1. Raise the Z1 coil up around the coil nest into position. It may be advisable to employ a third person for this step.
2. While holding the coil in position bolt it to the X coils with 1" threaded spacers, hex machine screws, and lock washers as shown in detail B of Fig. 11.
3. Secure the Z1 coil to the Y coils with 2 1/4" threaded spacers, hex machine screws, and lock washers as shown in detail C of Fig. 2-6.
4. Repeat steps 1-3 for the Z2 coil.

This completes assembly of the X, Y and Z coils.

#### **2.4.3 Magnetometer Sensor Installation**

1. Carefully unpack the CCM-3 Coil Control Magnetometer sensor and install it on the supplied vertical upright that attaches to the top of the X axis coil assembly.
2. For the time being, leave the sensor cable coiled up.

#### **2.4.4 Podium Mounting**

1. Locate the geometric center of the Helmholtz coil system.
2. Place the pedestal at the center of the coil system so that the hole in the center of the pedestal top surface is in line with the Z-axis centerline (vertical axis).
3. Rotate the pedestal about its vertical axis until it is oriented as shown in Fig. 2.
4. Attach the base of the pedestal to the floor using the four mounting holes.

#### **2.4.5 Magnetometer Sensor Installation**

1. Remove the four 10-32 3/4" aluminum screws from the sensor mounting holes on the top of the working surface of the pedestal.
2. Carefully unpack the CCM-3 Coil Control Magnetometer sensor and install it on the central vertical upright as shown in Fig. 2.
3. For the time being, leave the sensor cable coiled up inside the pedestal.

#### **2.4.6 Coil System Wiring**

Refer to Fig. 2-8.

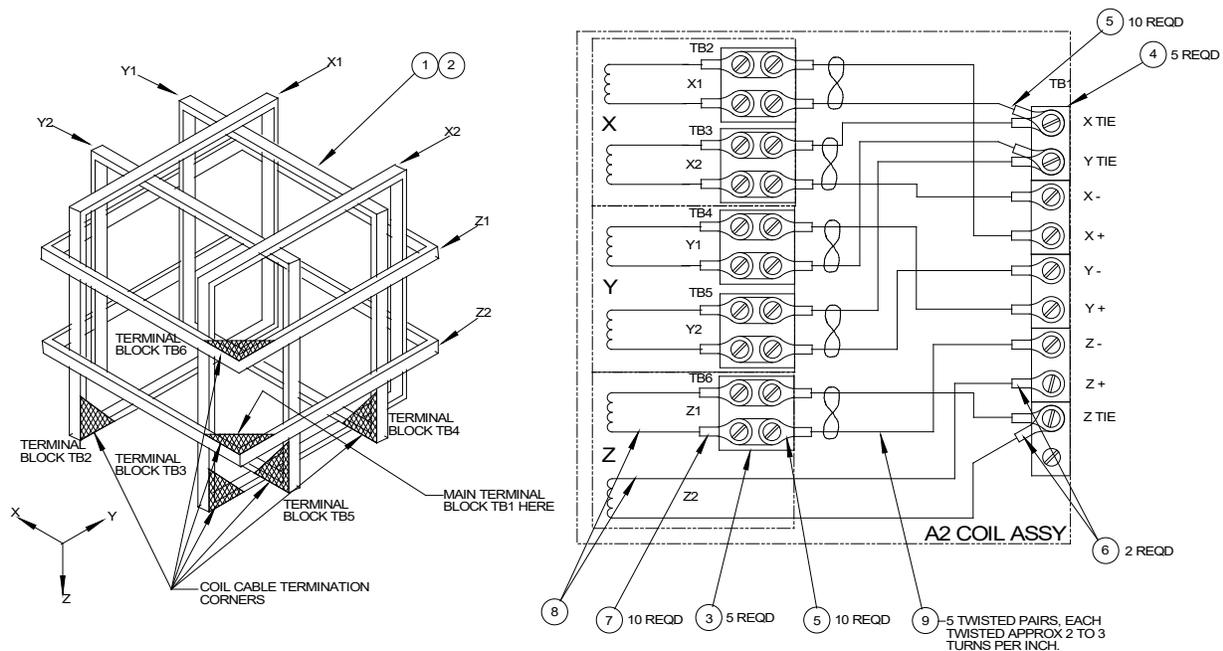


Figure 2-8 HCS01 Coil Assembly wiring.

The pairs of wire that connect the coil winding terminal blocks to the main terminal block are all in place on the various coil frames. At the most, cable clamps on the end of the wire segments have been opened to permit separation of the coils. All wire lugs and all terminal blocks have been labeled. Reconnection is a matter of routing the wires over the cable tie wire mounts, connecting them to the terminal blocks, and adding cable ties where applicable.

1. The X1 wire pair will be found secured by four cable clamps to the south or front side of the Z2 coil frame. Connect its left-hand ends to the corresponding terminals on the X1 coil frame. Route it through the cable clamp on the X1 frame and close the clamp.
2. Route the right-hand end through the open clamp on the Z2 frame and connect the +X1 lug to the +X terminal on the main terminal block, tightening the screw. Connect the -X1 wire to the X Tie terminal on the main terminal block, but do not tighten the screw.
3. Route the X2 wire pair through the open clamp on the Z2 frame. Connect the -X2 lug to the -X terminal on the main block and tighten the screw. Connect the +X2 lugs to the X Tie terminal, and tighten down the screw on two lugs.
4. The Y1 wire pair will be found running through four cable clamps on the east side of the Z2 coil frame. Connect its right-hand lugs to the corresponding terminals on the Y1 block. Route it through the clamp on the Y1 frame and secure the clamp.

5. Route the left-hand end through the open clamp on the Z2 frame. Connect the +Y1 lug to the +Y terminal on the main block and tighten the screw. Connect the -Y1 lug to the Y Tie terminal, leaving the screw loosely tightened.
6. Route the Y2 wire pair through the open cable clamp on the Z2 frame and close the clamp. Connect the -Y2 lug to the -Y terminal and tighten the screw. Connect the +Y2 lug to the Y Tie terminal and tighten the screw on two lugs.
7. The Z1 wire pair will be found running through four cable clamps on the X2 frame. Run its upper end through the cable clamp on the Z1 frame and close the clamp. Connect the lugs on the upper end to the correspondingly labeled terminals on the Z1 coil.
8. Route the lower end of the Z1 wire pair through the open cable clamp on the Z2 frame. Close the clamp over three pairs of wire.
9. Connect the -Z1 lug to the -Z terminal on the main block and tighten the screw. Connect the +Z lug to the Z Tie terminal and tighten the screw on two lugs.
10. Check that the +Z2 lug is connected to the +Z terminal and that the screw is tight.

## **2.5 RACK ASSEMBLY**

### **2.5.1 Overview**

The HCS01 control electronics are enclosed in a standard 19" equipment rack. The rack can be placed beside the table or desk that supports the personal computer that is the system operator interface.

The final rack assembly contains a CCM-3 Coil Control Magnetometer electronics chassis, three Kepco Bipolar Operational Power Supply chassis, and a power distribution unit.

### **2.5.2 Rack Assembly**

Uncrate the rack and place it in its intended location if possible. It can be moved short distances after assembly, but its weight of about 400 pounds needs to be considered. The CCM-3 Coil Control Magnetometer, BOPs and Power Distribution Unit are already installed in the rack. The rack also contains the cables that attach the BOPs in the rack to the Helmholtz Coil subassembly. Figure 2-9 below is a cable diagram for the HCS01 system.

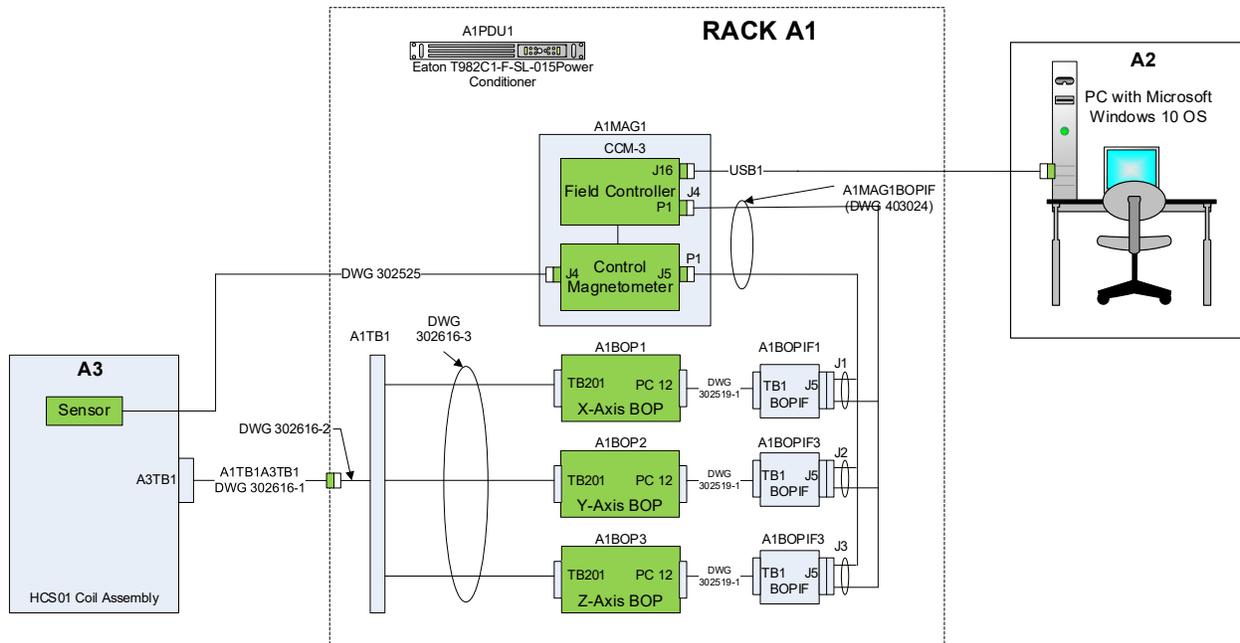
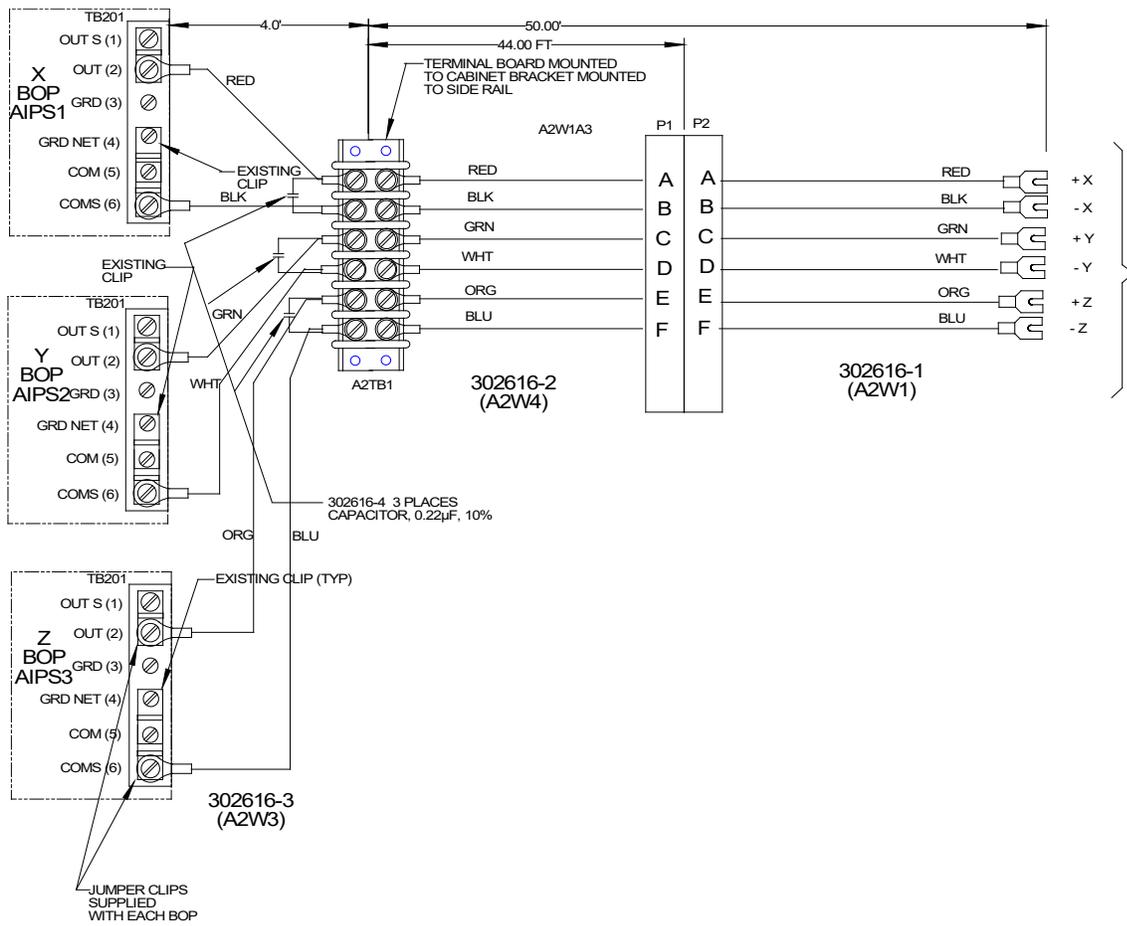


Figure 2-9 HCS01 cable diagram.

1. Uncrate the Bipolar Operational Power Supplies (BOP).
2. Remove the 10-32 screws and plastic backed washers from the tapped holes in the rack where they were placed for shipment. The three field BOPS are identical. They are to be installed in the order: lowest, middle, top. Each power supply has been marked X, Y or Z. They are to be placed alphabetically from the top down as shown in Fig. 1-1. The power supplies will slide easily into place on the brackets built into the rack. Secure each with four screws and washers.
3. Connect the color-coded wires from the terminal boards mounted on the left side of the rack (viewed from the rear) to the BOP TB201 terminals. First, remove one screw used to mount the BOPIF DUAL PCB to the BOP. Then rotate the BOPIF DUAL PCB to access TB201. Finally connect the wires and reattach the BOPIF DUAL PCB.
4. Untie the white cable in the rack and connect the Molex connectors to their associated field BOPIF DUAL PCBs and the 9-pin D connectors to CCM-3 J5 and P1.



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Figure 2-10 BOP to Helmholtz Coil Assembly wiring.

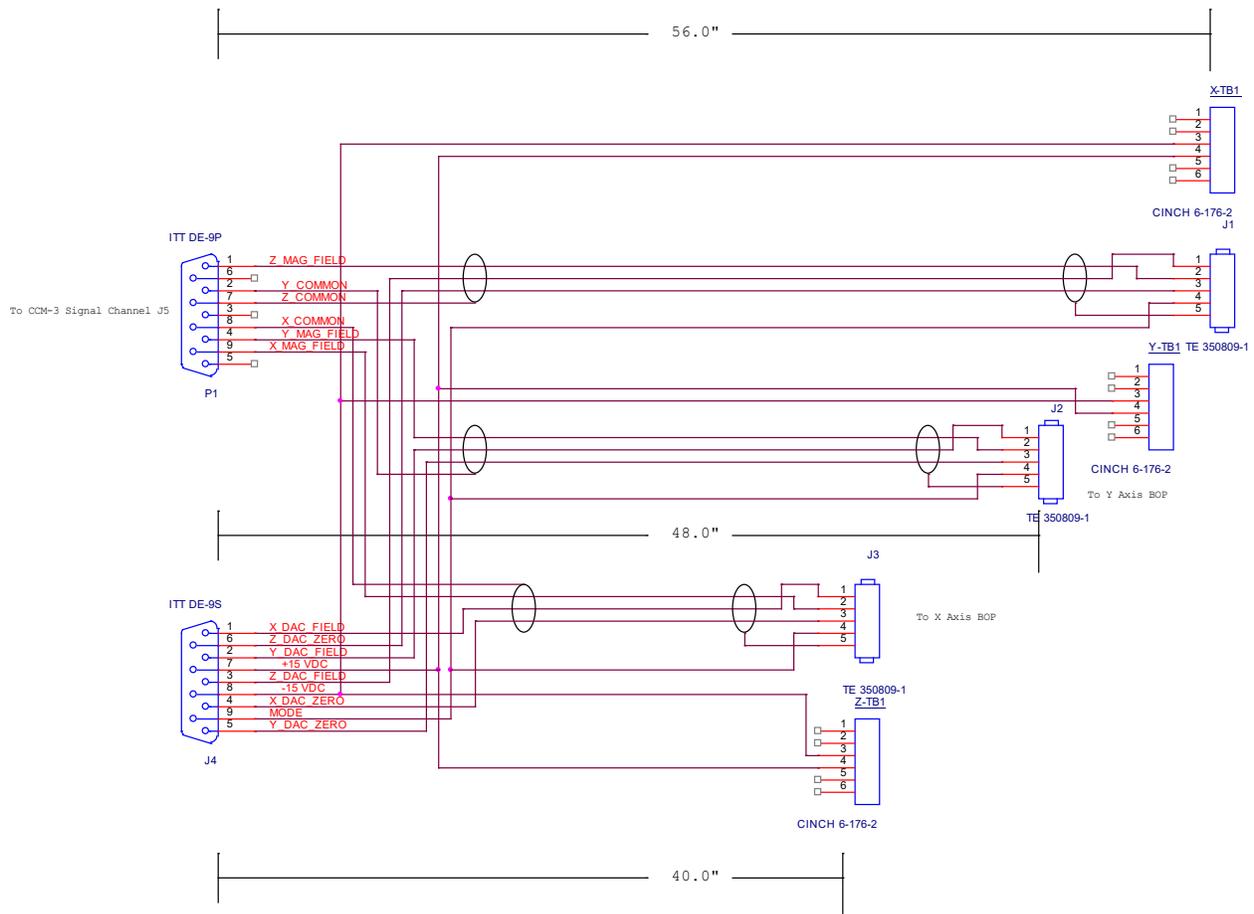


Figure 2-11 CCM-3 to BOP IF Cable Assembly

### 2.5.3 System Interconnection

Make sure that the main power cord from the power distribution unit is not connected to the wall outlet. Refer to Fig. 2-12.

1. Plug the power cords of the BOPs and the CCM-3 into the outlets on the back of the power distribution unit or UPS.
2. Connect the CCM-3 sensor cable to J2 of CCM-3. The sensor is mounted on a podium inside the coil assembly.
3. Connect the HCS01 coil assembly cable connector (P2) to the mating cable connector (P1) from the rack.
4. Connect CCM-3 J16 to any USB port of the PC.
5. Connect CCM-3 J4 and P1 to the Dual BOPIFs.

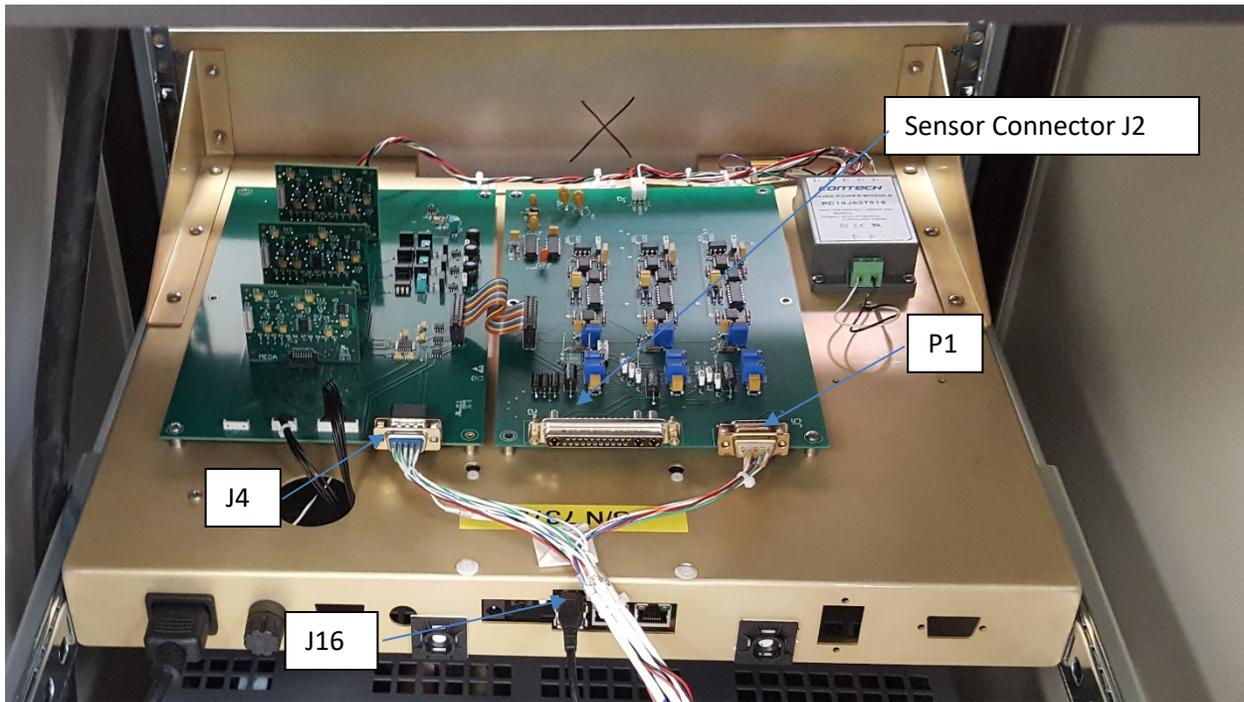


Figure 2-12 CCM-3 Connections

#### 2.5.4 CC6UL SBC Connections to CCM-3

Mounted on the bottom side of the chassis is a single board computer (Digi CC6UL SBC) that controls the operation of the system. The connections from the SBC to the Field Controller PCB are already installed when the system is delivered. In the event that the SBC fails and needs to be replaced use the following figure to disconnect and reconnect the SBC to the CCM-3 Field Controller PCB.

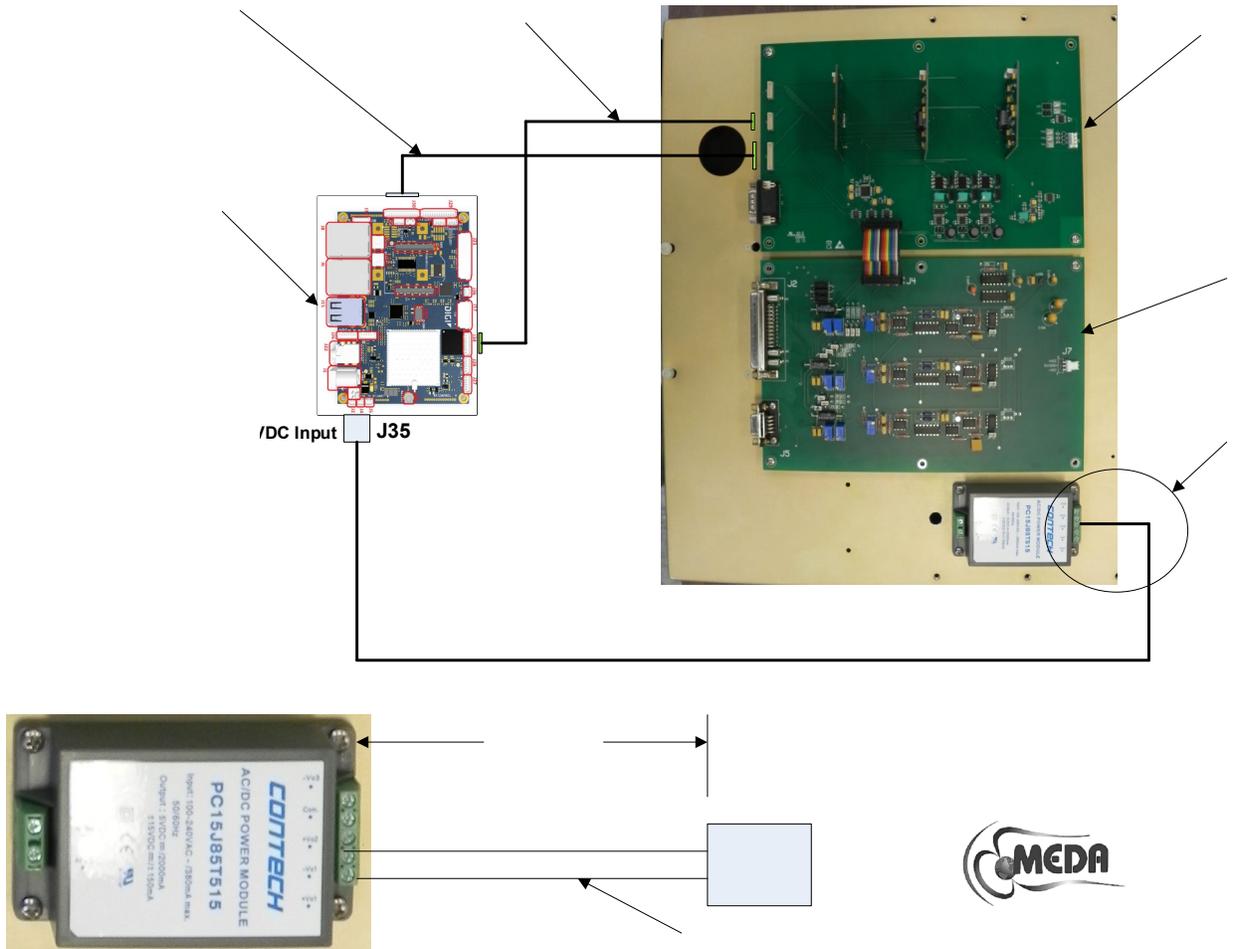


Figure 2-13 CC6UL to CCM-3 cable connections

The SBC can be purchased from MEDA. It needs to be programmed before it can be used.

## 2.6 PRELIMINARY CHECKOUT

Perform the following steps in the order given to verify that the HCS01 has been reassembled and is operating properly:

1. Turn off the BOP breakers on the power supplies and PDU.
2. Check the switch positions on the front panel of the BOPs. The switches should be in the following positions:

| <u>SWITCH</u>   | <u>POSITION</u> |
|-----------------|-----------------|
| MODE            | CURRENT         |
| VOLTAGE CONTROL | OFF             |
| CURRENT CONTROL | OFF             |

3. Turn on the PDU breaker. This will connect power to the BOPs.
4. Turn on the PC and wait 30 seconds for it to initialize.
5. Turn on the CCM-3 and wait 30 seconds for the CCM-3 to stabilize.
6. Place an RM100 Reference Magnetometer sensor on the HCS01 Calibration Fixture and calibration fixture on the podium. Align the sensor along the positive X-axis of the coil system (direction of arrows on X coil assembly).
7. Start the *HCS01 Front Panel program* (see Section 3.2).
8. After the *HCS01 Front Panel* screen appears, turn on the X BOP. The field measured by the magnetometer should drop to less than 2000 nT if the X-axis of the HCS01 is operating properly. The current and voltage meters on the X BOP should deflect slightly. If the deflection approaches full scale and the magnetometer reading increases then it is likely that the X-axis coils connected to the main field terminal block are reversed. Reverse the present connection and repeat the process described in the above paragraph.
9. Use the *HCS01 Front Panel* X-axis **Zero Adjust** control to set the X axis field to zero  $\pm 1$  nT.
10. Type 80000 into the X-axis **Field Magnitude** control. The magnetometer should indicate a positive field of approximately 80,000 nT.
11. Type -80000 into the X-axis **Field Magnitude** control. The magnetometer should indicate a negative field of approximately -80,000 nT.
12. Type 0 into the X-axis **Field Magnitude** control. The magnetometer should return to the zero-field measured in step 10.

13. Rotate the RM100 sensor so it is aligned with the positive Y axis and repeat steps 10 through 13 for the Y axis.
14. Rotate the RM100 sensor on the HCS01 Calibration Fixture so it is aligned with the negative Z field (sensor cable pointing down) and repeat steps 10 through 13. In this case the measured fields will have the opposite polarity to the applied fields.
15. Finally use the up and down arrows of the **Zero Adjust** controls to adjust the coil field to zero  $\pm 1$  nT in all three axes.

The zero adjustment settings can be stored in a file on the PC and restored from the file.

When the *HCS01 Front Panel* program is started, the zero settings are read from the HCS01 and the controls are initialized to these settings.

If the above steps were completed successfully, the HCS01 is ready for final adjustment and calibration using the procedures described in the following sections. A recalibration is in order any time the system is disassembled and reassembled in a new location. The recommended calibration interval is one year.

## 3 OPERATION

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### 3.1 HCS01 START-UP

The HCS01 should be started up using the following sequence, which assumes that the power switches on the PDU and BOPs are in the off position and the CCM-3, PC, and video display power switches are on:

1. Turn on the PDU. This will connect power to the BOPs, CCM-3 and the video display.
2. Start the *HCS01 Front Panel* program (see Section 3.2).
3. After the *HCS01 Front Panel* screen appears, turn on the BOPs one at a time. The order is unimportant.

The total transient current consumption of the HCS01 can be high enough to trip a 30-Ampere 120 VAC circuit breaker. The operating current is below the 30 Ampere trip point. The above procedure helps protect against tripping a circuit breaker.

### 3.2 HCS01 FRONT PANEL PROGRAM

The HCS01 include the *HCS01 Front Panel* program that can be used to control all the application of fields and adjustment of the zero fields in the center of the coil assembly. See Section 3.2.2 for instructions on installing and using the *HCS01 Front Panel* program. The program displays a virtual front panel on the PC and responds to mouse clicks and keyboard commands (see Fig. 3-1).

When the *HCS01 Front Panel* program is executed it displays the following screen. There are three tabs displayed from which the user can choose:

- **Front Panel** – The controls in this tab are used to apply magnetic fields and adjusting the field at the center of the HCS01 coil system to zero.
- **Calibrate** – The controls in this tab are used to calibrate the HCS01.
- **Report** – This tab is used to display reports generated by the *HCS01 Front Panel* program.

These tabs are discussed below.

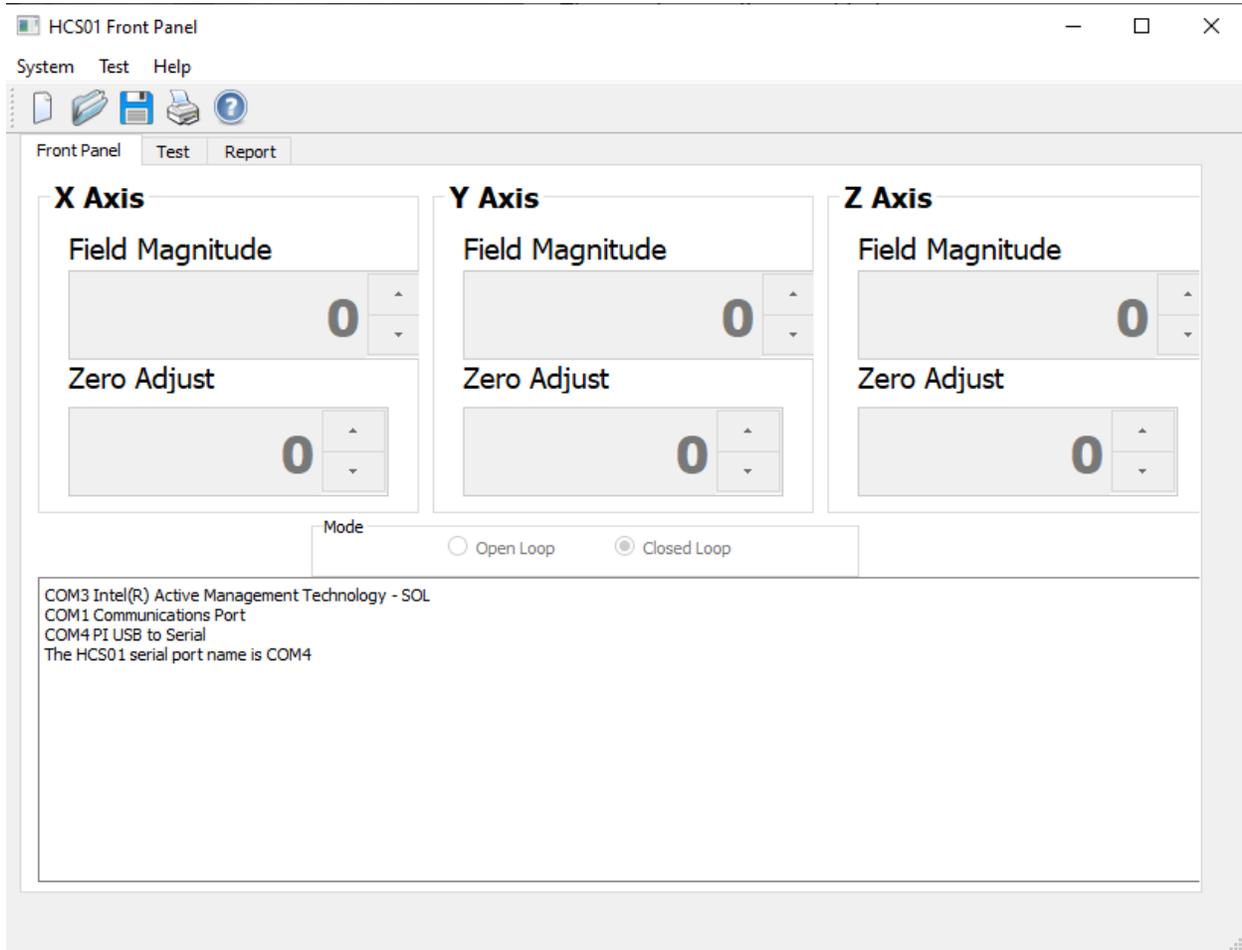


Figure 3-1 SSMMF Front Panel start screen

### 3.2.1 Minimum computer requirements

The computer requirements are:

- A computer running Microsoft Windows 10.
- Two available USB ports.

### 3.2.2 Installing HCS01 Front Panel Program

Use the following procedure to install the program.

All MEDA provided software and manuals are stored on a memory stick that is included with the HCS01 system.

1. Place the HCS01 memory stick in a USB port.
2. On the memory stick double click on the **HCS01\_vfp\_installer.exe** program.
3. Follow the instructions displayed on the screen.

The *HCS01 Front Panel* program will be placed in the *C:\MEDA* directory by default unless a different directory is chosen. Also an *HCS01 Front Panel* shortcut will be placed on the *Start* menu.

### 3.2.3 Starting HCS01 Front Panel

To start the HCS01 Front Panel program:

1. Click on *Start* followed by *MEDA* on the *Start* menu.
2. Select *HCS01\_vfp*.

The start screen of the *HCS01 Front Panel* virtual front panel will appear as shown in Fig. 3-1 above.

### 3.2.4 The Front Panel Tab

The **Front Panel** tab can be used to adjust the zero field within the test volume and to apply magnetic fields along the three axes of the HCS01. It can also be used to set the operating mode (Open Loop or Closed Loop).

#### 3.2.4.1 Zero Field Adjustment

The field in the test volume of the HCS01 can be adjusted to zero by using the **Zero Adjust** controls on the virtual front panel. A magnetometer is required to perform this task. The adjustment range is  $\pm 4000$  nT. Perform the following steps to set the field to zero:

1. Place the magnetometer sensor at the location in the test volume where the zero field is to be adjusted and align it along the positive direction of the axis being adjusted.
2. Set all Zero Adjustment controls to 0.
3. Type in the field value (in nT) measured by the magnetometer. This will produce a coarse zero offset correction.
4. Use the up and down arrows to the right of the **Zero** control until the magnetometer reads zero within  $\pm 1.0$  nT.
5. Rotate the sensor into the Y axis and repeat steps 3 and 4.
6. Rotate the sensor into the Z axis and repeat steps 3 and 4.

### **3.2.5 Saving and Restoring the Zero Adjustment Values**

After adjusting the zero valued they can be saved to or restored from a file. Use the procedures below.

#### ***3.2.5.1 Saving the Zero Adjustment Values***

To save the Zero Adjust controls values:

1. Click on the System menu.
2. Select Zeros->Save.

The Zero Adjust controls values will be save to a file. This operation can be performed for both Close Loop and Open Loop mode.

#### ***3.2.5.2 Restoring the Zero Adjustment Values***

To restore the Zero Adjust controls values:

1. Click on the System menu.
2. Select Zeros->Restore.

The saved Zero Adjust controls values will be displayed in the Zero Adjust controls.

### **3.2.6 Applying Fields**

To apply a field: Type a field value between -200000 and 200000 into the Field Magnitude control(s) or use the up and down arrows to the right of the text box. Do not put in any commas or spaces.

## **3.3 HCS01 POWER DOWN**

The following sequence should be used in powering down the HCS01:

1. Turn each of the BOPs off one at a time. The order is unimportant.
2. Turn the PDU switch to the off position.

# **4 THEORY OF OPERATION**

---

## **4.1 GENERAL**

The HCS01 is used to apply uniform, accurate and precise magnetic fields in the central region of the coil assembly. In Closed Loop mode the control system attenuates the effect of external magnetic field sources that might cause a disturbance in the region. The Earth's field is the major source attenuated by the HCS01.

In Open Loop mode there is no attenuation of the fields produced by external sources but the local ambient field is nulled for the nominal field values at the site. This mode is primarily used to perform magnetic cleanliness tests or calibrate magnetic sensor that are part of a subsystem that include other sensors that have magnetic properties.

The HCS01 provides separate operator controls for setting the zero fields and applied fields. In Closed Loop mode the Earth's field compensation function is controlled through a negative feedback loop that operates automatically without operator intervention. In Open Loop mode the nominal ambient field is compensated with a fixed value but the field in the coil assembly does not automatically adjust for changes in the ambient field.

## 4.2 CLOSE LOOP OPERATION

Figure 4-1 is a functional block diagram for one axis of the Closed Loop operating mode.

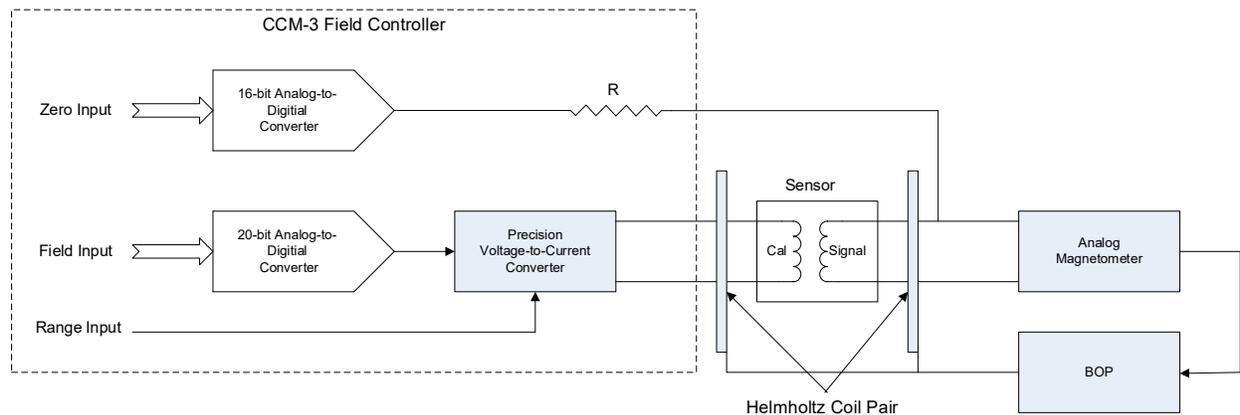


Figure 4-1 HCS01 X-Axis Closed Loop functional block diagram

In Closed Loop mode the overall operation of the HCS01 is based on a negative feedback loop which forces the magnetic field at the sensor near the center of the Helmholtz coil assembly to approach zero. The sensor of the control magnetometer is placed near the center of the Helmholtz coils. The output of the sensor is the sum of the ambient field and the Helmholtz coil field. It is processed and amplified by the magnetometer electronics and then applied to the input of a bipolar operational power supply (BOP). The BOP output drives the Helmholtz coils to produce a magnetic field at the sensor that opposes the ambient field. This causes the net field inside the Helmholtz coils to approach zero.

The forward gain of this negative feedback loop is very large. As a result, the large field of the Earth (40,000 to 75,000 nT) is reduced to only a few nT at the sensor location.

Because the control sensor is offset from the geometric center of the coil assembly, the field at the center may not be zero. The HCS01 has a control that can be used to adjust for this difference. This is discussed in Section 4.2.2.

Any changes in the Earth's field are automatically compensated through this negative feedback mechanism. In fact, any external disturbance that causes the ambient field to change uniformly will be attenuated. Thus, the field at the center of the coil assembly will be quite stable for large variations caused by external sources.

### 4.2.1 Field Application

The negative feedback loop forces the field at the sensor to a null. This characteristic is used to force the feedback loop to generate desired fields in the center of the coil assembly. A solenoid surrounding the sensor is driven by a stable 20-bit voltage-to-current converter. This produces a field at the sensor that the feedback system nulls. Since the solenoid field is local to the sensor (not present outside the solenoid), this process results in a field at the center of the coil assembly that is almost equal to the solenoid field. The difference (less than 1%) between the two is a result of the displacement of the sensor from the center of the coil assembly. This difference is eliminated through adjustments (see the Maintenance section).

The solenoid and current source used in the HCS01 are very stable and produce very linear and accurate fields.

The range of the applied field can be changed using the Range Input line. If the Range Input line is at a logic 0 (0 VDC) the field range is  $\pm 200,000$  nT with a resolution of 0.4 nT. If the Range Input line is at a logic 1 (3.3 VDC) the field range is  $\pm 10,000$  nT with a resolution of 0.02 nT. The HCS01 firmware automatically selects the field range based on the field value requested by the user.

### 4.2.2 ZERO FIELD ADJUSTMENT

A 16-bit DAC on the CCM-3 field controller motherboard connected through a resistor to the sensor input provides a fine adjustment of the zero fields at the center of the coil system. The current through the sensor signal winding creates a small local field at the sensor that the feedback system nulls, causing the field at the coil assembly center to change. The range of this fine adjustment is about  $\pm 4000$  nT.

## 4.3 OPEN LOOP OPERATION

Figure 4-2 is a functional block diagram of the Open Loop operating mode.

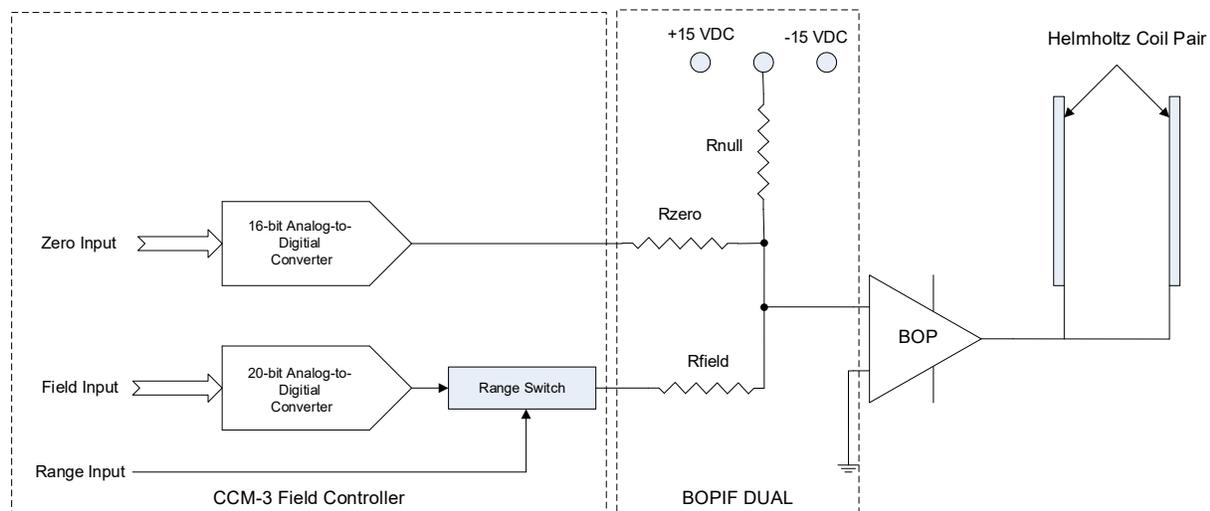


Figure 4-2 HCS01 X-Axis Open Loop functional block diagram

In Open Loop mode the control magnetometer is disabled. When the system is initially installed fixed currents in each of the coils are applied to cancel the local nominal ambient field in the test volume. Changes in the ambient field are not attenuated. The field in the test volume can be adjusted to zero at the beginning of a test but it may change during a test so it is important to monitor the field during a test to make sure changes in the ambient field do not affect result.

The range of the applied field can be changed using the Range Input line. If the Range Input line is at a logic 0 (0 VDC) the field range is  $\pm 200,000$  nT with a resolution of 0.4 nT. If the Range Input line is at a logic 1 (3.3 VDC) the field range is  $\pm 10,000$  nT with a resolution of 0.02 nT. The HCS01 firmware automatically selects the field range based on the field value requested by the user.

#### 4.3.1 Ambient Field Compensation

The local nominal ambient field along an axis is nulled by connecting a fixed resistor  $R_{\text{ambient}}$  from a fixed voltage (+15 VDC or -15 VDC) to the summing junction of the BOP input amplifier. The value of the resistor is selected based on the nominal ambient field magnitude. The fixed voltage connection is selected based on the polarity of the field being nulled.

#### 4.3.2 Field Application

The output of a 20-bit Digital-to-Analog Converter (DAC) in the CCM-3 field controller is connected through a resistor  $R_{\text{field}}$  to the summing junction of the BOP to generate the desired field in the test volume of the coil assembly. The value of the resistor is selected to produce a coarse scale factor ( $V_{\text{in}}$  to  $H_{\text{out}}$ ) required to apply the correct field in the test volume. During calibration this coarse scale factor is further trimmed so the system produces fields that meet the specified accuracy of the system.

#### 4.3.3 Zero Field Adjustment

A 16-bit DAC in the CCM-3 Field Controller is used to adjust the zero field in the test volume. The DAC output is connected to the summing junction of the BOP through a resistor  $R_{\text{zero}}$ . The resistor value is selected to produce a  $\pm 4000$  nT adjustment range.

## 5 REMOTE PROGRAMING

---

### 5.1 COMMAND PROCESSING

The following sections describe how the HCS01 processes commands received through the computer interface and what it sends back to the computer interface in response to the command. The HCS01 uses version 1999.0 SCPI (Standard Commands for Programmable Instruments) syntax described in the SCPI Consortium's standards. These standards can be obtained from:

SCPI Consortium  
2515 Camino del Rio South, Suite 340  
San Diego, CA 92108

They can also be downloaded from their web site: <http://www.ivifoundation.org/docs/scpi-99.pdf>

### 5.1.1 How SCPI Commands are Structured and Executed

The SCPI language uses a “tree” structure similar to the file structure used in computer operating systems. There is a set of top level or “root” commands. Beneath each root level command there are associated sublevel commands and so on. The complete path (root->subroot>subsubroot etc) must be specified before it can be executed. An example command is shown below:

```
:OUTPut:FIELD -15000 20000 -1200<CR>
```

The capital letters are required. The lower-case letters are optional. The command string is case insensitive. You can use either the abbreviated or the full command name but nothing else, otherwise you will generate an -113, “Undefined header” error.

In this example :OUTPut is the root command; :FIELD is a subcommand of OUTPut and the values following FIELD are the values of the X, Y and Z fields to apply. The <CR> at the end of the line indicates to the HCS01 that the command is complete and to process it. This command sets the values of the HCS01 fields.

The colon in the front of the first command indicates that it is a root command. If the root command is the first command in the string the colon is not needed.

### 5.1.2 Sending Multiple Commands in One Command String

Multiple commands can be included in the command string. The SCPI language uses a semicolon to separate the commands. An example follows:

```
:OUTPut:FIELD -15000 20000 -1200;:OUTPut:ZERO 250 -400 -550
```

This command string includes two commands separated by semicolons. The first command causes the HCS01 to apply the specified fields. The second command causes the HCS01 to apply the specified zero adjustment.

If an error occurs in executing the command, processing of the commands stops. The commands up to the point of an error are executed. Commands following an error are not executed. There are many possible sources of errors. The most common ones are syntax errors, missing parameters and parameter values that are out of bounds. Use the :SYST:ERR? Command to retrieve error messages.

In a command string that contains multiple commands, if the next command in the string is on the same level as the last substring the upper level portion of the path does not need to be included. The above command could have been entered as follows:

```
:OUTPut:FIELD -15000 20000 -1200;ZERO 250 -400 -550
```

Since FIELD and ZERO have the OUTPut path in common there is no need to repeat this path information in front of the ZERO command.

White space (spaces and tabs) is allowed anywhere within the command string. A white space is required between a command and its associated parameters such as -15000 in the above example.

Commands that have a ? at the end return information to the user’s computer.

### 5.1.3 How the Computer Receives Data

Some commands, such as :SYSTEM:CALibrate:SCALE?, return data. When a command returns data the data is followed by a <CR><LF> combination. For example the :SYSTEM:CALibrate:SCALE?, command would return

```
1.0004 0.9998 -1.0001<CR><LF>
```

where 1.0004 0.9998 -1.0001 are the values of the X, Y and Z scale factors.

White space may precede each value in the returned string and the first significant digit.

## 5.2 COMMAND DESCRIPTIONS

Table 6-1 is a summary of all of the HCS01 remote commands. The commands that start with \* are called common commands which are common to all instruments that implement the SCPI command structure. The root commands are shown in red.

Table 5-1 Summary of remote HCS01 commands

| Command                         | Parameters              | Description   |
|---------------------------------|-------------------------|---|
| :OUTPut<br>:FIELD?              |                         | Returns the X, Y and Z field values in nT. Integer format.  |
| :OUTPut<br>:FIELD               | <value> <value> <value> | Sets the X, Y and Z field values in nT. Integer format.<br>Range: -200000 to +200000  |
| :OUTPut<br>:ZERO?               |                         | Returns the X, Y and Z zero adjust values in nT. Integer format.  |
| :OUTPut<br>:ZERO                | <value> <value> <value> | Sets the X, Y and Z zero adjustment values in nT. Integer format.<br>Range: -4000 to +4000  |
| :SOURce<br>:MODE                | {LIST FIX HALT}         | Starts and stops field generation using the stored list.<br>LIST – starts generation<br>FIX – stops generation<br>HALT – stops generation at the end of a cycle |
| :SOURce<br>:MODE?               |                         | Returns the mode.<br>0 – LIST<br>1 – FIX<br>2 - HALT  |
| :SOURce<br>:LIST<br>:AMPLitude  | <value>                 | Multiplier for the list values.<br>Default – 1.0  |
| :SOURce<br>:LIST<br>:AMPLitude? |                         | Returns the multiplier value.   |
| :SOURce<br>:LIST<br>:CLEAR      |                         | Clears the field vector list  |
| :SOURce<br>:LIST<br>:COUNT      | <value>                 | Number of times to repeat the list. A value of 0 means continuously.<br>Default – 0.<br>Maximum - 255   |
| :SOURce<br>:LIST<br>:COUNT?     |                         | Returns the number of times the list will be repeated.<br>0 - continuously  |
| :SOURce<br>:LIST<br>:DELEte     | <List name>             | Deletes the list stored locally in the field controller non-volatile memory.  |
| :SOURce<br>:LIST<br>:DWELl      | <value>                 | Dwell time between outputting of list values in milliseconds.<br>Minimum – 4 ms.  |
| :SOURce<br>:LIST                |                         | Returns the dwell time in milliseconds.   |

| Command                           | Parameters                       | Description   |
|-----------------------------------|----------------------------------|---|
| :DWELI?                           |                                  |   |
| :SOURce<br>:LIST<br>:FIELD        | <X value> <Y value><br><Z value> | Loads one vector into the list buffer and increments the list index. The list should be cleared before starting a new list.<br>Range: -200,000 nT to 200,000 nT         |
| :SOURce<br>:LIST<br>:FIELD?       |                                  | Returns 16 vectors starting at the point specified by the SOURce:LIST;QUERy value.  |
| :SOURce<br>:LIST<br>:LOAD<br>:LOC | <List name>                      | Loads the named list from the local non-volatile storage and places the data into the list buffer. The data in the list must be in comma separated values (CSV) format. |
| :SOURce<br>:LIST<br>:LOAD<br>:USB | <List name>                      | Loads the named list from the USB drive and places the data into the list buffer. The data in the list must be in comma separated values (CSV) format.                  |
| :SOURce<br>:LIST<br>:POINT?       |                                  | Returns the number of vectors stored in the list buffer.  |
| :SOURce<br>:LIST<br>:QUERy        | <value>                          | Returns the index pointing to the first vector in the list buffer that will be returned using the :SOURce:LIST:FIELD? Command.  |
| :SOUR<br>:LIST<br>:SAVE<br>:LOC   | <List name>                      | Save the current list buffer data to local non-volatile storage.  |
| :SOUR<br>:LIST<br>:SAVE<br>:USB   | <List name>                      | Save the current list buffer data to the USB drive.   |
| :SOURce<br>:LIST<br>:SHOW         | {LOC USB}                        | Displays the lists that are stored locally (LOC) or on the USB drive.   |
| :SOURce<br>:VECTor<br>:ABORt      |                                  | Stops the generation of the vector wave.  |
| :SOURce<br>:VECTor<br>:DCYClE     | <value>                          | Sets the duty cycle of the vector SQUARE wave or RAMP.<br>Range: 0% to 100%   |
| :SOURce<br>:VECTor<br>:DCYClE?    |                                  | Returns the current value of the duty cycle.  |
| :SOURce<br>:VECTor<br>:DURAtion   | <value>                          | Set show many cycles of the vector wave to output. 0 specifies continuous.<br>Range 0 to 1000 cycles (Default is 0)   |

| Command                           | Parameters         | Description  |
|-----------------------------------|--------------------|--|
| :SOURce<br>:VECTor<br>:DURAtion?  |                    | Returns the number of vector wave cycles that will be output.  |
| :SOURce<br>:VECTor<br>:FREQuency  | <value>            | Specifies the frequency of the vector wave.<br>Range: 0.001 Hz to 5 Hz.  |
| :SOURce<br>:VECTor<br>:FREQuency? |                    | Returns the current frequency setting in Hz.   |
| :SOURce<br>:VECTor<br>:FUNction   | {SINE SQUARE RAMP} | Specifies the type of vector wave to output.   |
| SOURce<br>:VECTor<br>:FUNction?   |                    | Returns the current function setting.<br>0 – SINE<br>1 – SQUARE<br>2 – RAMP  |
| :SOURce<br>:VECTor<br>:INITiate   |                    | Starts outputting the vector wave.   |
| :SOURce<br>:VECTor<br>:MAGNitude  | <value>            | Set the peak magnitude of the vector wave in nT.<br>Range: 0 to 200000 nT.   |
| :SOURce<br>:VECTor<br>:MAGNitude? |                    | Returns the peak magnitude of the vector wave in nT.   |
| :SOURce<br>:VECTor<br>:PHI        | <value>            | Sets the angle of the vector projected onto the XY plan relative to the X axis.<br>Range: 0 to 360 degrees.  |
| :SOURce<br>:VECTor<br>:PHI?       |                    | Returns the angle of the vector projected onto the XY plan relative to the X axis.   |
| :SOURce<br>:VECTor<br>:THETa      | <value>            | Sets the angle between the vector and the XY plane.<br>Range: -90 to +90 degrees.  |
| :SOURce<br>:VECTor<br>:THETa?     |                    | Returns the angle between the vector and the XY plane.   |
| :SOURce<br>:VECTor<br>VARiable    | {R PHI THETA}      | Specifies the vector wave variable that is cycled (time dependent).<br>R – vector magnitude<br>PHI – the angle of the vector projected onto the XY plane relative to the X axis.<br>THETA – The angle between the vector and the XY plane. |

| Command  | Parameters              | Description   |
|--|-------------------------|---|
| <b>:SOURce</b><br><b>:VECTor</b><br><b>VARiable?</b>               |                         | Returns the vector wave variable that is cycled (time dependent).<br>0 – R<br>1 – PHI<br>2 - THETA        |
| <b>:STATus</b><br><b>:OPERation</b><br><b>[:EVENT]?</b>            |                         | Returns the Operation Event Register value.   |
| <b>:STATus</b><br><b>:OPERation</b><br><b>:CONDition?</b>          |                         | Returns the Operation Condition Register value.   |
| <b>:STATus</b><br><b>:OPERation</b><br><b>:ENABle</b>              | <value>                 | Places <value> into the Operation Event Enable Register, which must be an integer between 0 and 32767.    |
| <b>:STATus</b><br><b>:OPERation</b><br><b>:ENABle?</b>             |                         | Returns the Operation Event Enable Register value.  |
| <b>:STATus</b><br><b>:QUEStionable</b><br><b>[:EVENT]?</b>         |                         | Returns the Questionable Event Register value.  |
| <b>:STATus</b><br><b>:QUEStionable</b><br><b>:CONDition?</b>       |                         | Returns the Questionable Condition Register value.  |
| <b>:STATus</b><br><b>:QUEStionable</b><br><b>:ENABle</b>           | <value>                 | Places <value> into the Questionable Event Enable Register, which must be an integer between 0 and 32767. |
| <b>:STATus</b><br><b>:PRESet</b>                                   |                         | Clears the Operation and Questionable Event Enable registers.   |
| <b>SYSTem</b><br><b>:CALibrate</b><br><b>:ENABle?</b>              |                         | Returns the calibration Enable state. 0 = disabled.<br>1 = enabled.                                       |
| <b>SYSTem</b><br><b>:CALibrate</b><br><b>:ENABle</b>               | {ON OFF}                | Enable/disables updating the calibration factors.<br>0-OFF, 1-ON  |
| <b>SYSTem</b><br><b>:CALibrate</b><br><b>: SCALe?</b>              |                         | Returns the three zero adjust scale factors: X, Y and Z in floating point format d.dddddd.                |
| <b>SYSTem</b><br><b>:CALibrate</b><br><b>:SCALe</b>                | <value> <value> <value> | Set the X, Y and Z zero adjust scale factors in that order.<br><value> - d.ddddd.                         |
| <b>SYSTem</b><br><b>:CALibrate</b><br><b>:VECTor</b><br><b>:X?</b> |                         | Returns the X axis direction cosine in floating point format d.dddddd.<br><a[0][0]> <a[0][1]> <a[0][2]>   |

| Command                                       | Parameters              | Description   |
|---|-------------------------|---|
| <b>SYSTem</b><br>:CALibrate<br>:VECTor<br>:X  | <value> <value> <value> | Sets the X axis direction cosine in floating point notation.  |
| <b>SYSTem</b><br>:CALibrate<br>:VECTor<br>:Y? |                         | Returns the Y axis direction cosine in floating point format d.dddddd.<br><a[1][0]> <a[1][1]> <a[1][2]>   |
| <b>SYSTem</b><br>:CALibrate<br>:VECTor<br>:Y  | <value> <value> <value> | Sets the Y axis direction cosine in floating point notation d.dddddd.   |
| <b>SYSTem</b><br>:CALibrate<br>:VECTor<br>:Z? |                         | Returns the Z axis direction cosine in floating point format d.dddddd.<br><a[2][0]> <a[2][1]> <a[2][2]>   |
| <b>SYSTem</b><br>:CALibrate<br>:VECTor<br>:Z  | <value> <value> <value> | Sets the Z axis direction cosine in floating point notation d.dddddd.   |
| <b>SYSTem</b><br>:CALibrate<br>:STORe         |                         | Stores the calibration factors in the calibration file. Saves a backup before storing the new data.   |
| : <b>SYSTem</b><br>:ERRor<br>[:NEXT]?         |                         | Returns the error number and short text message of the error stored in the error buffer. Error numbers are stored in the error buffer in first-in-first-out order. The :NEXT is optional. |
| : <b>SYSTem</b><br>:MODE                      | {OL CL}                 | Set the system mode.<br>OL – Open Loop<br>CL – Closed Loop  |
| : <b>SYSTem</b><br>:MODE?                     |                         | Returns the system mode state.<br>0 – Open Loop<br>1 – Closed Loop  |
| : <b>SYSTem</b><br>:RANGe                     | {ON OFF}                | Turns auto-range on or off. In the off state the field resolution is 0.4 nT. Default is ON.   |
| : <b>SYSTem</b><br>:RANGe?                    |                         | Returns the auto-range state.   |
| : <b>SYSTem</b><br>:VERsion?                  |                         | Returns the SCPI version to which the HCS01 conforms.   |
| <b>*CLS</b>                                   |                         | Clears all event registers summarized in the Status Byte Register.  |
| <b>*ESE</b>                                   | <value>                 | Places <value> into the Event Status Enable Register, which must be an integer between 0 and 255.   |

| Command | Parameters | Description   |
|---------|------------|---|
| *ESE?   |            | Returns the value stored in the Event Status Enable Register.   |
| *ESR?   |            | Returns the value stored in the Event Status Register and clears the register.  |
| *IDN?   |            | Returns the HCS01 Field Controller identity string<br>MEDA,HCS01,nnnnnn,n.n<br>Where nnnnnn is the serial number and n.n is the firmware version.   |
| *OPC    |            | Sets the Operation Complete bit in the Standard Event Status Register when parsed.  |
| *OPC?   |            | Returns an ASCII 1 when parsed.   |
| *RST    |            | Rests field and zero adjustments to 0.  |
| *SRE    | <value>    | Places <value> into the Service Request Enable Register, which must be an integer between 0 and 255. The values of bit one and bit six are ignored since they are not used.   |
| *SRE?   |            | Returns the value stored in the Service Request Enable Register with bits one and six set to zero.  |
| *STB?   |            | Returns the value stored in the Status Byte Register.   |
| *TST?   |            | Performs a self-test of the HCS01 Field Controller. If errors occurred an error message is pushed onto the error stack describing the error. Use “SYST:ERR?” to see if errors occurred. If errors occurred continue to use “SYST:ERR?” to display the error(s) until the message returned is “0, No Error”. |
| *WAI    |            | Non-operational in the HCS Field Controller. Recognized but not executed.   |

## 5.2.1 OUTput Commands

The OUTPUT commands are used to apply fields and adjust the coil system zeros.

### 5.2.1.1 OUTput:Field Command

Gets or sets the specified field to the X, Y and Z axes of the coil system.

**Syntax:** Short Form: OUTP:FIEL                      Long Form: OUTPUT:FIELD

**Parameters:**    <X Value> <Y Value> <Z Value>    Range: -200,000 to +200,000 nT  
Value specified with integers.

**Query:** Short Form: OUTP:FIEL?                      Long Form: OUTPUT:FIELD?

**Query Response:** Returns the currently applied field vector XYZ component values. The values are comma separated.

If a specified field value is out of range, a -222 “Data out of range” error will be generated and the field values will not be updated.

### 5.2.1.2 *OUTput:ZERO Command*

Sets or gets the coil system XYZ zero adjustment values.

**Syntax:** Short Form: OUTP:ZERO                      Long Form: OUTPUT:ZERO

**Parameters:**     <X Value> <Y Value> <Z Value>    Range: -4000 to +4000 nT  
Value is specified with integers.

**Query:** Short Form: OUTP:ZERO?                      Long Form: OUTPUT:ZERO?

**Query Response:** Returns the currently applied XYZ zero adjustment values. The values are comma separated.

If a specified zero value is out of range, a -222 “Data out of range” error will be generated and the zero values will not be updated.

## 5.2.2 *SOURce:LIST Commands*

The SOURce:LIST commands allow the user to specify up to 1000 magnetic field vectors that will be applied sequentially at a specified update interval (minimum of 4 milliseconds). The lists can be repeated up to 255 times.

The most straight forward method for loading vectors into a list is to use the SOURce:LIST:FIELD command. Each time a new vector is loaded, a counter is incremented that keeps track of the number of vectors in the list. Once all of the vectors have been loaded into the list, the SOURce:MODE LIST command can be used to start outputting the vectors in the list at the current dwell interval specified by the SOURce:LIST:DWELL command. The minimum dwell interval is 4 milliseconds. The SOURce:MODE FIX command immediately stops the outputting of vectors. The SOURce:MODE HALT command stops the outputting of the vectors at the completion of the list.

The list can also be loaded from a list saved in the local non-volatile memory or from a USB drive. Lists are stored as text files in comma separated value (CSV) format. Excel and MATLAB can be used to generate the compatible files.

The following subsections describe each of the commands.

### 5.2.2.1 *SOURce:LIST:AMPLitude Command*

Sets or gets the amplitude of the applied vector. The list values are multiplied by this value.

**Syntax:** Short Form: SOUR:LIST:AMPL                      Long Form: SOURCE:LIST:AMPLITUDE

**Parameters:**     <Digits with explicit decimal point>                      Range: -200000 to 200000

**Query:** Short Form: SOUR:LIST:AMPL?

Long Form: SOURCE:LIST:AMPLITUDE?

**Query Response:** value of the amplitude parameter.

If a specified amplitude value is out of range, a -222 “Data out of range” error will be generated and the amplitude value will not be updated.

### 5.2.2.2 *SOURce:LIST:CLEAr Command*

Clears the list of all data. Should be executed before creating a new list.

**Syntax:** Short Form: SOUR:LIST:CLEAr

Long Form: SOURCE:LIST:CLEAR

**Parameters:** None

**Query:** None

**Query Response:** None

### 5.2.2.3 *SOURce:LIST:COUNT Command*

Specifies the number of times the list should be repeated. A count of 0 indicates the list should be repeated infinitely until stopped by one of the SOURce:MODE commands.

**Syntax:** Short Form: SOUR:LIST:COUNT

Long Form: SOURCE:LIST:COUNT

**Parameters:** <Integer> Range: 0 to 255

**Query:** Short Form: SOUR:LIST:COUNT?

Long Form: SOURCE:LIST:COUNT?

**Query Response:** value of the count parameter.

If a specified count value is out of range, a -222 “Data out of range” error will be generated and the count value will not be updated.

### 5.2.2.4 *SOURce:LIST:DELEte Command*

Deletes a named list stored in the local non-volatile memory.

**Syntax:** Short Form: SOUR:LIST:DELE

Long Form: SOURCE:LIST:DELETE

**Parameters:** <List name>

**Query:** None

**Query Response:** None

### 5.2.2.5 *SOURce:LIST:DWELl Command*

Specifies the dwell time between applying the next point in the list.

**Syntax:** Short Form: SOUR:LIST:DWEL

Long Form: SOURCE:LIST:DWELL

**Parameters:** <Integer> Range: 4 to 65,535 milliseconds

**Query:** Short Form: SOUR:LIST:DWEL?

Long Form: SOURCE:LIST:DWELL?

**Query Response:** value of the dwell parameter in milliseconds.

If a specified dwell value is out of range, a -222 “Data out of range” error will be generated and the dwell value will not be updated.

#### 5.2.2.6 *SOURce:LIST:FIELD Command*

Specifies the XYZ components of a field vector to be stored in a list. The number of vectors in the list is incremented. Before creating a new list make sure to clear the list with the SOURce:LIST:CLEAr command to reset the vector count.

**Syntax:** Short Form: SOUR:LIST:FIEL

Long Form: SOURCE:LIST:FIELD

**Parameters:** <X Value> <Y Value> <Z Value> Range: -200,000 to +200,000 nT  
Value is specified with digits and a decimal point.

**Query:** Short Form: SOUR:LIST:FIEL?

Long Form: SOURCE:LIST:FIEL?

**Query Response:** Returns the sixteen vectors stored in the list starting at the vector specified by the SOURce:LIST:QUERy command.

If a specified field value is out of range, a -222 “Data out of range” error will be generated and the field vector will not be added to the list.

#### 5.2.2.7 *SOURce:LIST:LOAD:LOC Command*

Loads a named list stored in the local non-volatile memory and places it into the list buffer. Before loading a list use the SOURce:LIST:CLEAr command to empty the list buffer.

**Syntax:** Short Form: SOUR:LIST:LOAD:LOC

Long Form: SOURCE:LIST:LOAD:LOC

**Parameters:** <List name>

**Query:** None

**Query Response:** None

If the list does not exist, a -228 – “List does not exist” error will be generated. To find what lists are stored in the non-volatile memory use the SOURce:LIST:SHOW command with the LOC parameter.

#### 5.2.2.8 *SOURce:LIST:LOAD:USB Command*

Loads a named list stored on the USD disc and places it into the list buffer. Before loading a list use the SOURce:LIST:CLEAr command to empty the list buffer.

**Syntax:** Short Form: SOUR:LIST:LOAD:USB

Long Form: SOURCE:LIST:LOAD:USB

**Parameters:** <List name>

**Query:** None

**Query Response:** None

If the list does not exist, a -228 – “List does not exist” error will be generated. To find what lists are stored on the USB drive use the SOURce:LIST:SHOW command with the USB parameter.

#### **5.2.2.9 SOURce:LIST:POINT? Command**

Returns the number of points in the list buffer.

**Syntax:** Short Form: SOUR:LIST:POIN?                      Long Form: SOURCE:LIST:POINT?

**Parameters:**        None

#### **5.2.2.10 SOURce:LIST:QUERY Command**

Sets and gets the value that points to the vector to be returned when the SOURce:LIST:FIELD? command is execute.

**Syntax:** Short Form: SOUR:LIST:QUER                      Long Form: SOURCE:LIST:QUERY

**Parameters:**        <Integer>            Range: 1 to 1000

**Query:** Short Form: SOUR:LIST:QUER?                      Long Form: SOURCE:LIST:QUERY?

**Query Response:** value that point to the first vector in the list which will be returned using the SOURce:LIST:FIELD? command.

If a specified query value is out of range, a -222 “Data out of range” error will be generated and the query value will not be updated.

#### **5.2.2.11 SOURce:LIST:SAVE:LOC Command**

Stores the current list buffer vector data to the local non-volatile memory.

**Syntax:** Short Form: SOUR:LIST:SAVE:LOC                      Long Form: SOURCE:LIST:SAVE:LOC

**Parameters:**        <List name>

**Query:**                None

**Query Response:** None

#### **5.2.2.12 SOURce:LIST:SAVE:USB Command**

Stores the current list buffer vector data to the USB disk.

**Syntax:** Short Form: SOUR:LIST:SAVE:USB                      Long Form: SOURCE:LIST:SAVE:USB

**Parameters:**        <List name>

**Query:**                None

**Query Response:** None



The duration of the periodic vector can be specified using the `SOURce:VECTor:DURAtion` command. The range is 0 to 1000 cycles. A duration of 0 means that the periodic vector will be generated continuously until aborted by the `SOURce:VECTor:ABORt` command.

The periodic vector is superimposed on the static field specified by the User. The static field can be changed at any time using the `OUTP:FIELD` command. Also the magnitude of the periodic vector can be changed at any time using the `SOURce:VECTor:MAGNitude` command. The  $\phi$  and  $\theta$  values can be changed while the periodic vector is being generated but will not have any effect until the periodic vector has been aborted and a new periodic vector is generated.

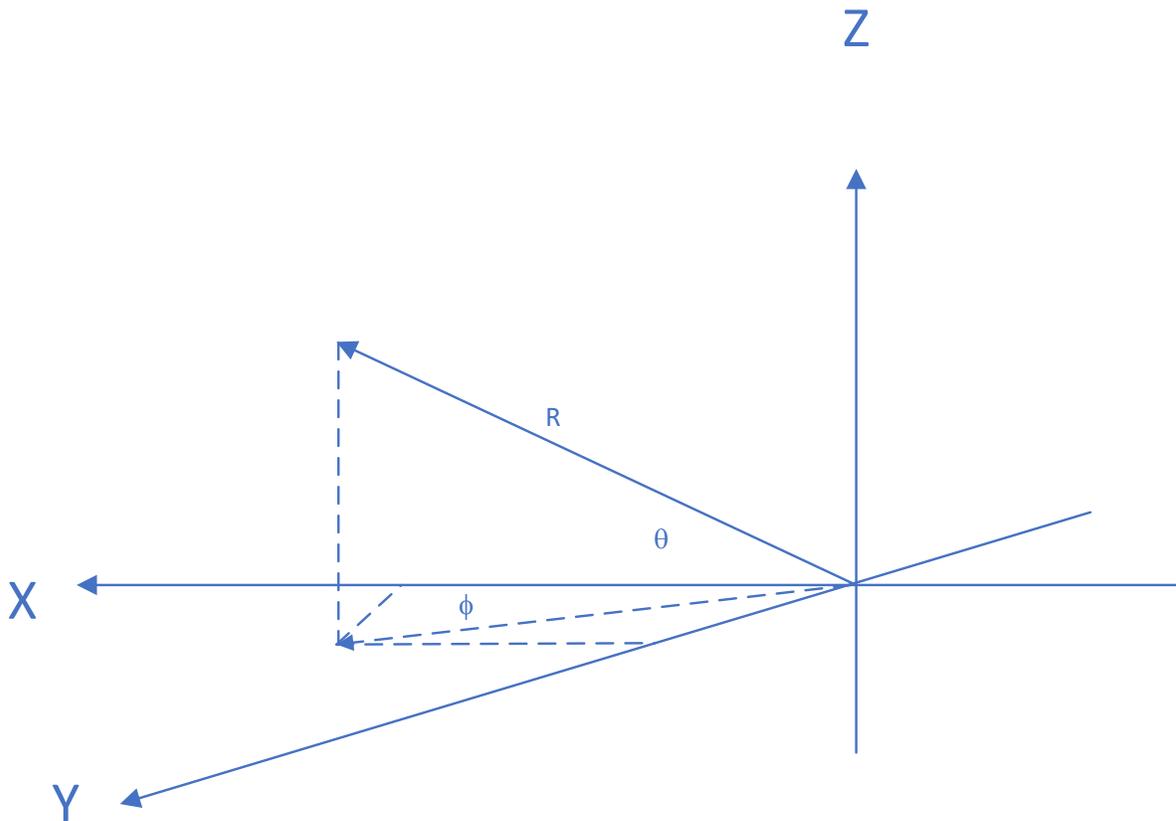


Figure 5-1 Vector component definition

The following subsections provide a description of each command.

#### 5.2.3.1 *SOURce:VECTor:ABORt Command*

Immediately stops the generation of the periodic vector function and returns the field vector to its original static value present before generating the periodic vector function.

**Syntax:** Short Form: `SOUR:VECT:ABOR` Long Form: `SOURCE:VECTOR:ABORT`

**Parameters:** None

**Query:** None

**Query Response:** None

### 5.2.3.2 *SOURce:VECTor:DCYcle Command*

Set or gets the duty cycle of the Square wave or Ramp periodic vector in percent.

**Syntax:** Short Form: SOUR:VECT:DCYC                      Long Form: SOURCE:VECTOR:DCYCLE

**Parameters:**     <Digits with explicit decimal point>                      Range: 0 to 100

**Query:** Short Form: SOUR:VECT:DCYC?                      Long Form: SOURCE:VECTOR:DCYCLE?

**Query Response:** value of the duty cycle in percent.

The default duty cycle is 50% so a Square wave has equal positive and negative durations and the Ramp is a triangular shape.

A duty cycle of 0% for a Square wave produces a static field of -MAGNITUDE and a duty cycle of 100% produces a static field of +MAGNITUDE.

A duty cycle of 0% for a Ramp produce a negative ramp throughout the period. A duty cycle of 100% for a Ramp produces a positive ramp throughout the period.

If a specified duty cycle value is out of range, a -222 "Data out of range" error will be generated and the duty cycle value will not be updated.

### 5.2.3.3 *SOURce:VECTor:DURation Command*

Sets or gets the number of cycles the periodic vector will perform. A 0 value indicates that the periodic vector will continue indefinitely until aborted.

**Syntax:** Short Form: SOUR:VECT:DURA                      Long Form: SOURCE:VECTOR:DURATION

**Parameters:**     <Integer >                      Range: 0 to 1000

**Query:** Short Form: SOUR:VECT:DURA?                      Long Form: SOURCE:VECTOR:DURATION?

**Query Response:** The number of cycles that will be generated.

If a specified duration value is out of range, a -222 "Data out of range" error will be generated and the duration value will not be updated.

### 5.2.3.4 *SOURce:VECTor:FREQuency Command*

Set or gets the frequency of the periodic vector.

**Syntax:** Short Form: SOUR:VECT:FREQ                      Long Form: SOURCE:VECTOR:FREQUENCY

**Parameters:**     < Digits with explicit decimal point >                      Range: 0.001 to 5 Hz

**Query:** Short Form: SOUR:VECT:FREQ?

Long Form: SOURCE:VECTOR:FREQUENCY?

**Query Response:** The frequency of the periodic vector.

The number of points per cycle depends on the frequency. If the frequency is 5 Hz there will be 50 points per cycle. The dwell time between output levels is 4 milliseconds for frequencies down to 0.003 Hz. The maximum number of points per cycle is 65,535.

If a specified frequency value is out of range, a -222 "Data out of range" error will be generated and the frequency value will not be updated.

### 5.2.3.5 *SOURce:VECTor:FUNctioN Command*

Set or gets the periodic vector function.

**Syntax:** Short Form: SOUR:VECT:FUNC

Long Form: SOURCE:VECTOR:FUNCTION

**Parameters:** {SINE|SQUARE|RAMP} SINE – Sine wave function

SQUARE – Square wave function

RAMP – Ramp function

**Query:** Short Form: SOUR:VECT:FUNC?

Long Form: SOURCE:VECTOR:FUNCTION?

**Query Response:** 0 – Sine 1 – Square 2 – Ramp

The shape of the Square wave and Ramp depend on the duty cycle. See the SOURce:VECTor:DCYClE command.

### 5.2.3.6 *SOURce:VECTor:INITiate Command*

Start the generation of the periodic vector.

**Syntax:** Short Form: SOUR:VECT:INIT

Long Form: SOURCE:VECTOR:INITiate

**Parameters:** None

**Query:** None

**Query Response:** None

The periodic vector will be generated as long as the specified number of cycles specified in the SOURce:VECTor:DURAtion command have not been reached. If duration is 0 the periodic vector will continue repeating until the SOURce:VECTor:ABORt command is execute.

### 5.2.3.7 *SOURce:VECTor:MAGNitude Command*

Sets or gets the magnitude (R) of the periodic vector.

**Syntax:** Short Form: SOUR:VECT:MAGN

Long Form: SOURCE:VECTOR:MAGNITUDE

**Parameters:** < Digits with explicit decimal point > Range: 0 to 200,000 nT

**Query:** Short Form: SOUR:VECT:MAGN?                      Long Form: SOURCE:VECTOR:MAGNITUDE?

**Query Response:** The magnitude of the periodic vector.

The periodic vector is superimposed on the static vector field. If the value of the static field plus the periodic field is greater than 200,000 nT or less than -200,000 nT the resulting field will be clipped.

If a specified magnitude value is out of range, a -222 "Data out of range" error will be generated and the magnitude value will not be updated.

### 5.2.3.8 *SOURce:VECTor:PHI Command*

Sets or gets the value of  $\phi$  (see Fig. 5-1).

**Syntax:** Short Form: SOUR:VECT:PHI                      Long Form: SOURCE:VECTOR:PHI

**Parameters:**     < Digits with explicit decimal point >     Range: 0 to 360 degrees

**Query:** Short Form: SOUR:VECT:PHI?                      Long Form: SOURCE:VECTOR:PHI?

**Query Response:** The value of  $\phi$ .

If a specified  $\phi$  value is out of range, a -222 "Data out of range" error will be generated and the  $\phi$  value will not be updated.

### 5.2.3.9 *SOURce:VECTor:THETa Command*

Sets or get the value of  $\theta$  (see Fig. 5-1).

**Syntax:** Short Form: SOUR:VECT:THETA                      Long Form: SOURCE:VECTOR:THETA

**Parameters:**     < Digits with explicit decimal point >     Range: 0 to 360 degrees

**Query:** Short Form: SOUR:VECT:THET?                      Long Form: SOURCE:VECTOR:THETA?

**Query Response:** The value of  $\theta$ .

If a specified  $\theta$  value is out of range, a -222 "Data out of range" error will be generated and the  $\theta$  value will not be updated.

### 5.2.3.10 *SOURce:VECTor:VARiable Command*

Gets or sets the period vector variable that will be time dependent.

**Syntax:** Short Form: SOUR:VECT:VARI                      Long Form: SOURCE:VECTOR:VARiable

**Parameters:**     {R|PHI|THETA} See Fig. 5-1 for an definition of the parameters

**Query:** Short Form: SOUR:VECT:FUNC?                      Long Form: SOURCE:VECTOR:FUNCTION?

**Query Response:** 0 – R 1 – PHI 2 – THETA



#### 5.2.4.1.3 SYSTem:CALibrate:VECTor:X Command

Set or gets the direction cosine vector components of the system X axis. These values are used to correct the correct the alignment of the coil system axes.

**Syntax:** Short Form: SYST:CAL:VECT:X                      Long Form: SYSTEM:CALIBRATE:VECTOR:X

**Parameters:**     <X Value> <Y Value> <Z Value> Default (1.0 0.0 0.0)  
Value format is sd.dddddd.

**Query:** Short Form: SYST:CAL:VECT:X?                      Long Form: SYSTEM:CALIBRATE:VECTOR:X?

**Query Response:** Returns the direction cosine vector components of the coil system X axis.

#### 5.2.4.1.4 SYSTem:CALibrate:VECTor:Y Command

Set or gets the direction cosine vector components of the system Y axis. These values are used to correct the correct the alignment of the coil system axes.

**Syntax:** Short Form: SYST:CAL:VECT:Y                      Long Form: SYSTEM:CALIBRATE:VECTOR:Y

**Parameters:**     <X Value> <Y Value> <Z Value> Default (0.0 1.0 0.0)  
Value format is sd.dddddd.

**Query:** Short Form: SYST:CAL:VECT:Y?                      Long Form: SYSTEM:CALIBRATE:VECTOR:Y?

**Query Response:** Returns the direction cosine vector components of the coil system Y axis.

#### 5.2.4.1.5 SYSTem:CALibrate:VECTor:Z Command

Set or gets the direction cosine vector components of the system Z axis. These values are used to correct the correct the alignment of the coil system axes.

**Syntax:** Short Form: SYST:CAL:VECT:Z                      Long Form: SYSTEM:CALIBRATE:VECTOR:Z

**Parameters:**     <X Value> <Y Value> <Z Value> Default (0.0 0.0 1.0)  
Value format is sd.dddddd.

**Query:** Short Form: SYST:CAL:VECT:Z?                      Long Form: SYSTEM:CALIBRATE:VECTOR:Z?

**Query Response:** Returns the direction cosine vector components of the coil system Z axis.

#### 5.2.4.1.6 SYSTem:CALibrate:STORe Command

Stores the calibration factors in non-volatile memory in the HCS01 field controller. Saves a backup copy before storing the new data. The SYSTem:CALibrate:ENABLE ON command must be executed before the calibration factors can be stored.

**Syntax:** Short Form: SYST:CAL:STOR                      Long Form: SYSTEM:CALIBRATION:STORE

**Parameters:**     None

**Query:**             None



### 5.3 ERROR MESSAGE SUMMARY

Table 5-4 below lists all of the possible error numbers and associated messages.

*Table 5-2 Error numbers and messages*

| <b>Error Number</b> | <b>Error Message</b>      |
|---------------------|---------------------------|
| -101                | Invalid character         |
| -102                | Syntax error              |
| -103                | Invalid separator         |
| -104                | Data type error           |
| -109                | Missing parameter         |
| -112                | Program mnemonic too long |
| -113                | Undefined header          |
| -151                | Invalid string data       |
| -158                | String not allowed        |
| -203                | Command protected         |
| -222                | Data out of range         |
| -223                | List buffer full          |
| -224                | Illegal parameter value   |
| -225                | List buffer empty         |
| -226                | Could not open list       |
| -227                | No lists                  |
| -228                | List does not exist       |
| -230                | Data corrupt or stale     |
| -350                | Queue overflow            |
| -365                | Time out error            |
| 522                 | Output buffer overflow    |
| 523                 | File does not exist       |
| 524                 | X field DAC MAX failure   |
| 525                 | X field DAC MIN failure   |
| 526                 | Y field DAC MAX failure   |
| 527                 | Y field DAC MIN failure   |
| 528                 | Z field DAC MAX failure   |
| 529                 | Z field DAC MIN failure   |
| 530                 | X zero DAC MAX failure    |
| 531                 | X zero DAC MIN failure    |
| 532                 | Y zero DAC MAX failure    |
| 533                 | Y zero DAC MIN failure    |
| 534                 | Z zero DAC MAX failure    |
| 535                 | Z zero DAC MAX failure    |

## 5.4 STATUS STRUCTURE

The HCS01 conforms to the SCPI status register structure. There are three event registers with associated event enable registers that feed a Status Byte register that summarizes the status of the HCS01. This structure is illustrated in Fig. 5-2.

### 5.4.1 Status Byte Register

The bits in the Status Byte Register (SBR) indicate the state of the event registers, the Output Queue and the Error Queue. The SRQ bit depends on the state of the SRB and the Service Request Enable (SRE) register. The SRQ bit is controlled by the SRE register. The SBR bits are logically ANDed (&) with the corresponding bits of the SRE register and the results ORed to determine the state of the SRQ bit. The bits in the SBR do not latch. Their state (0 or 1) indicates the state of their associated event register or queue.

Use the \*STB? query command to read the condition of the SBR. Then read the specific event register using the appropriate query command to determine the cause of an event. The query commands are listed in Table 5-3.

### 5.4.2 Questionable Event Register

The Questionable Event Register (QER) indicates events that compromise the measurements being made. Only two events are indicated:

Bit 8 - Calibration Error. Set if an error occurred during the self-test that occurs when the HCS01 is first turned on or in response to the \*TST command.

Bit 9 - Over Range. Set whenever the measurement results in an over range error (NA)

The bits in the QER are latched until reset by reading the register or issuing a \*CLS command. Use the :STAT:QUES? command to read the contents of the QER.

The state of the QER is reported to the SBR based on the contents of the Questionable Event Enable (QEE) register. The QER bits are ANDed with the corresponding QEE register bits and the results ORed to determine the state of the QSB bit in the SBR. Enable the reporting of a QER event by setting the corresponding bit in the QEE to 1. Use the :STAT:QUES:ENAB command to set the bits in the QEE (see Table 5-1).

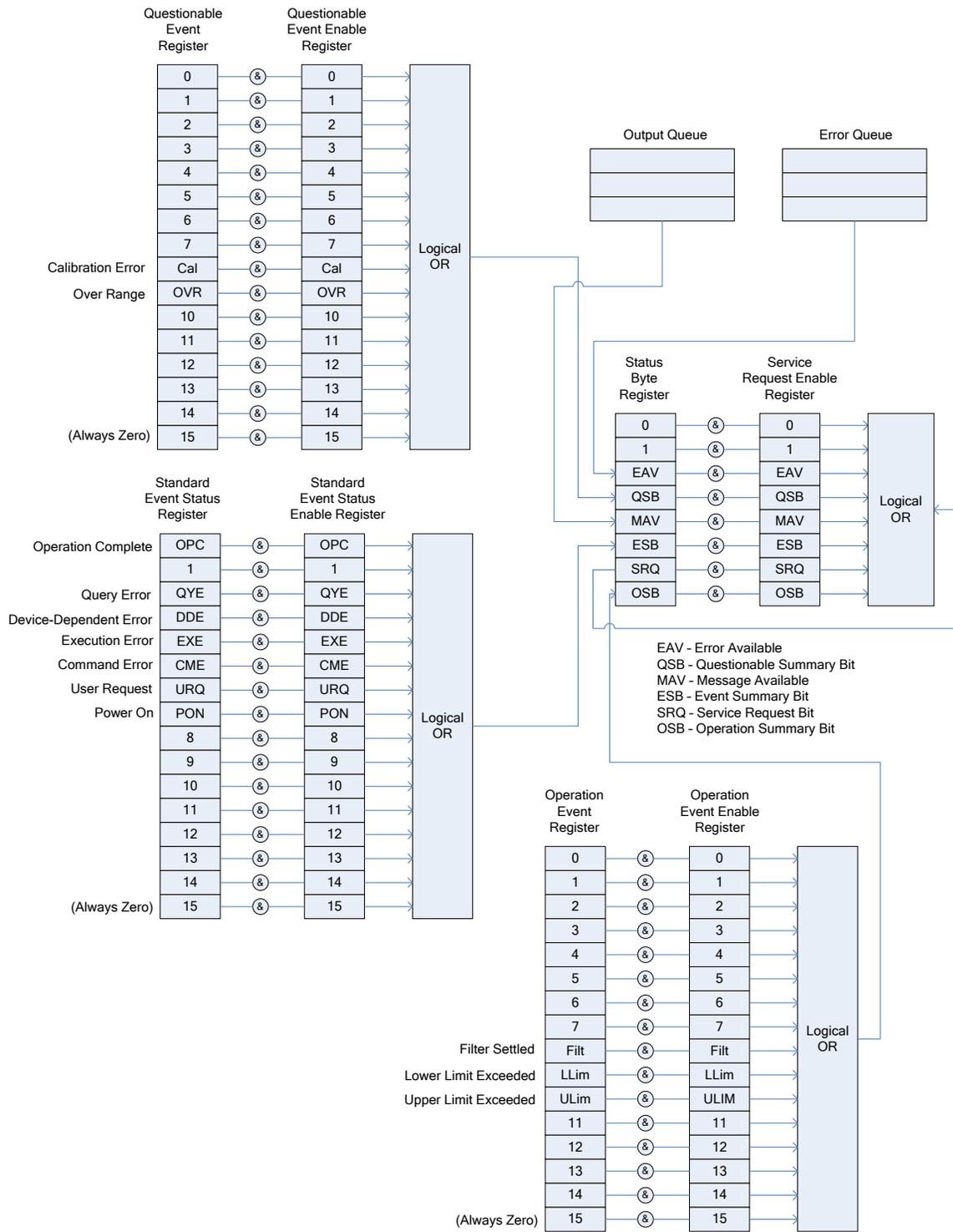


Figure 5-2 HCS01 Status Register Structure

### 5.4.3 Standard Event Status Register

The Standard Event Status (ESR) register bits correspond to the following events:

Bit 0 – Operation Complete (OPC). Indicates that all pending operations are complete. This bit is set only in response to the \*OPC command.

Bit 1 – Not used.

Bit 2 – Query Error. Not used.

Bit 3 – Device Dependent Error. Not used.

Bit 4 – Execution error. Set if there was an error in executing a command.

Bit 5 – Command Error. Set when there was an error in the command sent to the HCS01.

Bit 6 – User request. Not used.

Bit 7 – Power On (PON). This bit indicates that the HCS01 was turned off and then back on since the last time this register was read.

The bits in the ESR are latched until reset by reading the register or issuing a \*CLS command. Use the \*ESR? command to read the contents of the ESR.

The state of the ESR is reported to the SBR based on the contents of the Standard Event Status Enable (ESE) register. The ESR bits are ANDed with the corresponding ESE register bits and the results ORed to determine the state of the ESB bit in the SBR. Enable the reporting of an ESR event by setting the corresponding bit in the ESE to 1. Use the \*ESE command to set the bits in the ESE register (see Table 5-1).

### 5.4.4 Operation Event Register

The Operation Event Status (OES) register bits correspond to the following events:

Bit 0 through Bit 7 – Unused.

Bit 8 – Filter Settled. Indicates that the running average filter has settled.

Bit 9 – Lower Limit Failed. Set when the lower limit test fails.

Bit 10 – Upper Limit Failed. Set when the lower limit test fails.

Bit 11 through Bit 15 – Unused.

The bits in the OES register are latched until reset by reading the register or issuing a \*CLS command. Use the :STAT:OPER? command to read the contents of the OES register.

The state of the OES register is reported to the SBR based on the contents of the Operation Event Status Enable (OESE) register. The OES register bits are ANDed with the corresponding OESE register bits and the results ORed to determine the state of the OSB bit in the SBR. Enable the reporting of an ESR event by

setting the corresponding bit in the ESE to 1. Use the :STAT:OPER:ENAB command to set the bits in the OESE register (see Table 5-1).

#### 5.4.5 Clearing the Event and Event Enable Registers

The event and event enable registers are cleared when the HCS01 is first turned on. These registers can be cleared programmatically using the following commands:

\*CLS – Resets all bits in the Standard, Operation and Questionable Event Registers.

:STAT:PRES – Resets all bits in the Operation and Questionable Event Enable Registers.

\*ESE 0 – Resets the Event Status Enable Register.

## 6 MAINTENANCE

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### 6.1 GENERAL

The HCS01 requires very little maintenance. The major maintenance activity is the periodic calibration of the system. All replaceable parts are at the printed circuit board module level or higher. In the event of a failure, the HCS01 can be repaired quickly by substituting a spare unit for the failed module. It is highly recommended that a complete set of spare modules be maintained on site. This will reduce down time.

System recalibration is necessary after replacement of any module. Certain modules such as the bipolar power supplies should not affect the calibration, but maintenance of calibration integrity dictates that a recalibration is in order.

The following sections provide information that is required by qualified technical personnel to adjust and calibrate the HCS01. Any questions about these procedures should be directed to MEDA, Inc.

### 6.2 ADJUSTMENTS

This section describes the adjustments that are necessary to restore the HCS01 system to its specified performance.

The following equipment is needed to perform the calibration and zero adjustments.

1. HCS01 calibration fixture (not included).
2. RM100 single axis Reference Magnetometer (not included).
3. FVM400 Three Axis vector magnetometer (not included).
4. *HCS01 Front Panel* software (included).

#### 6.2.1 Closed Loop HCS01 Scale Factor and Zero Adjustment

The HCS01 scale factors should be adjusted after replacing, repairing or adjusting any module in the system. Scale factor adjustment involves the application and measurement of magnetic fields and adjustment of variable resistors.

The scale factor and zero correction require a very accurate magnetometer and a high-resolution Multimeter. The recommended magnetometer is an RM100 manufactured by MEDA, Inc. It has a full-scale range of  $\pm 100,000$  nT and an accuracy of 0.01% of the reading. The recommended Multimeter is a Keithley Model 2701. These adjustments should be made after the HCS01 has been powered on for at least 30 minutes. The facility should be at its nominal temperature.

Below is a picture of the interior of the CCM-3 control magnetometer.

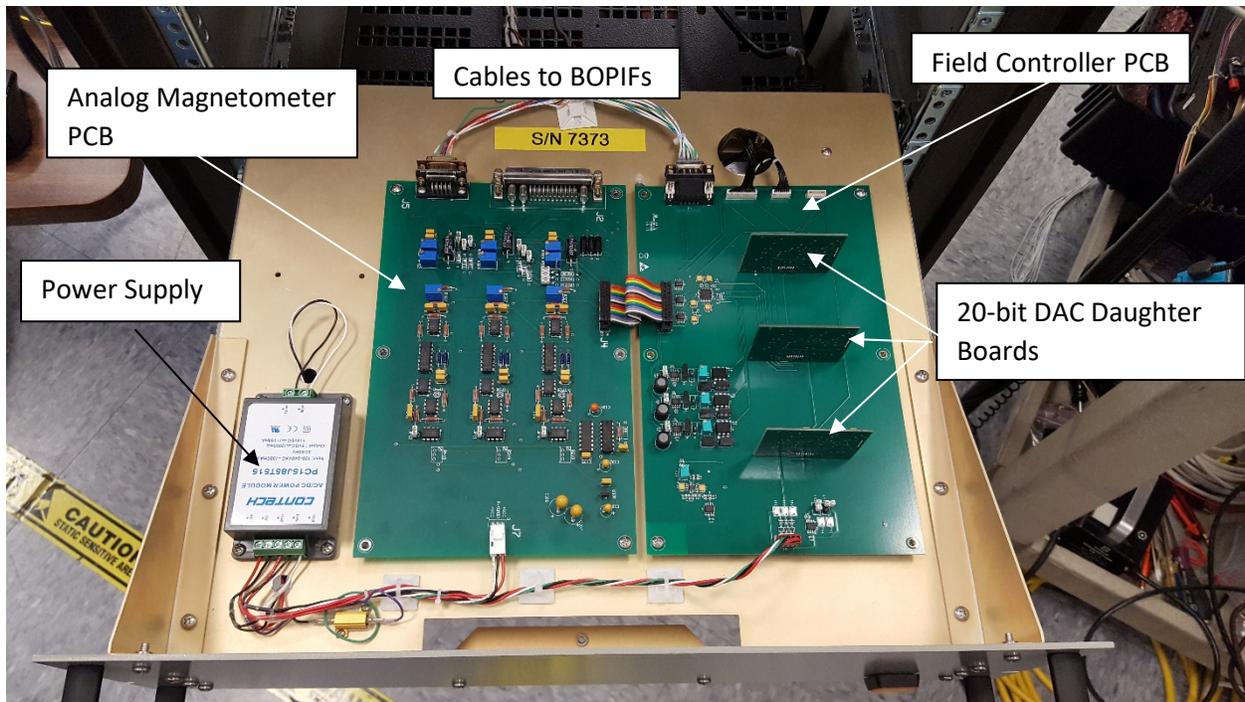


Figure 6-1 Top view of the inside of the CCM-3

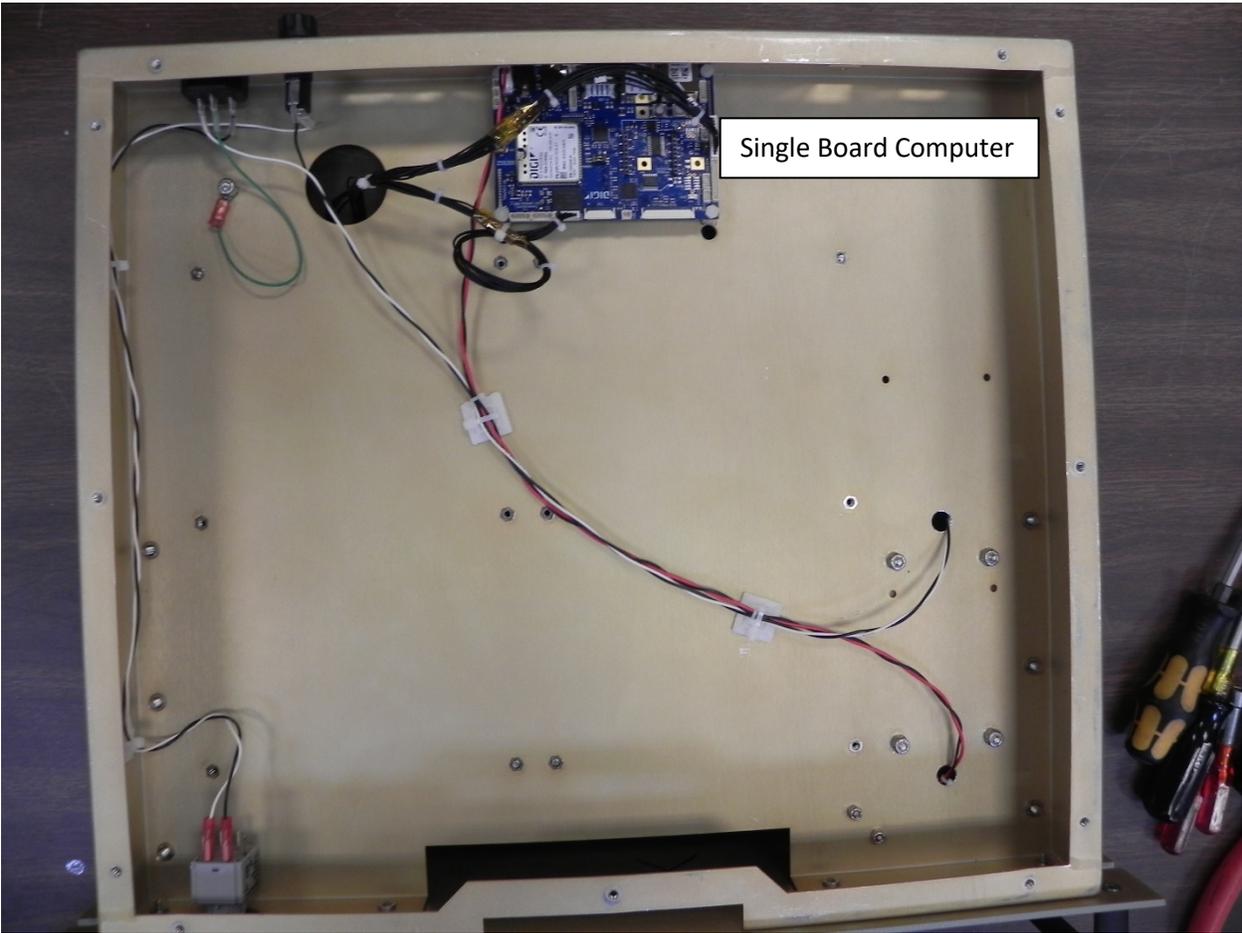


Figure 6-2 Bottom view of the inside of the CCM-3

All adjustments are made on the CCM-3 field controller PCB.

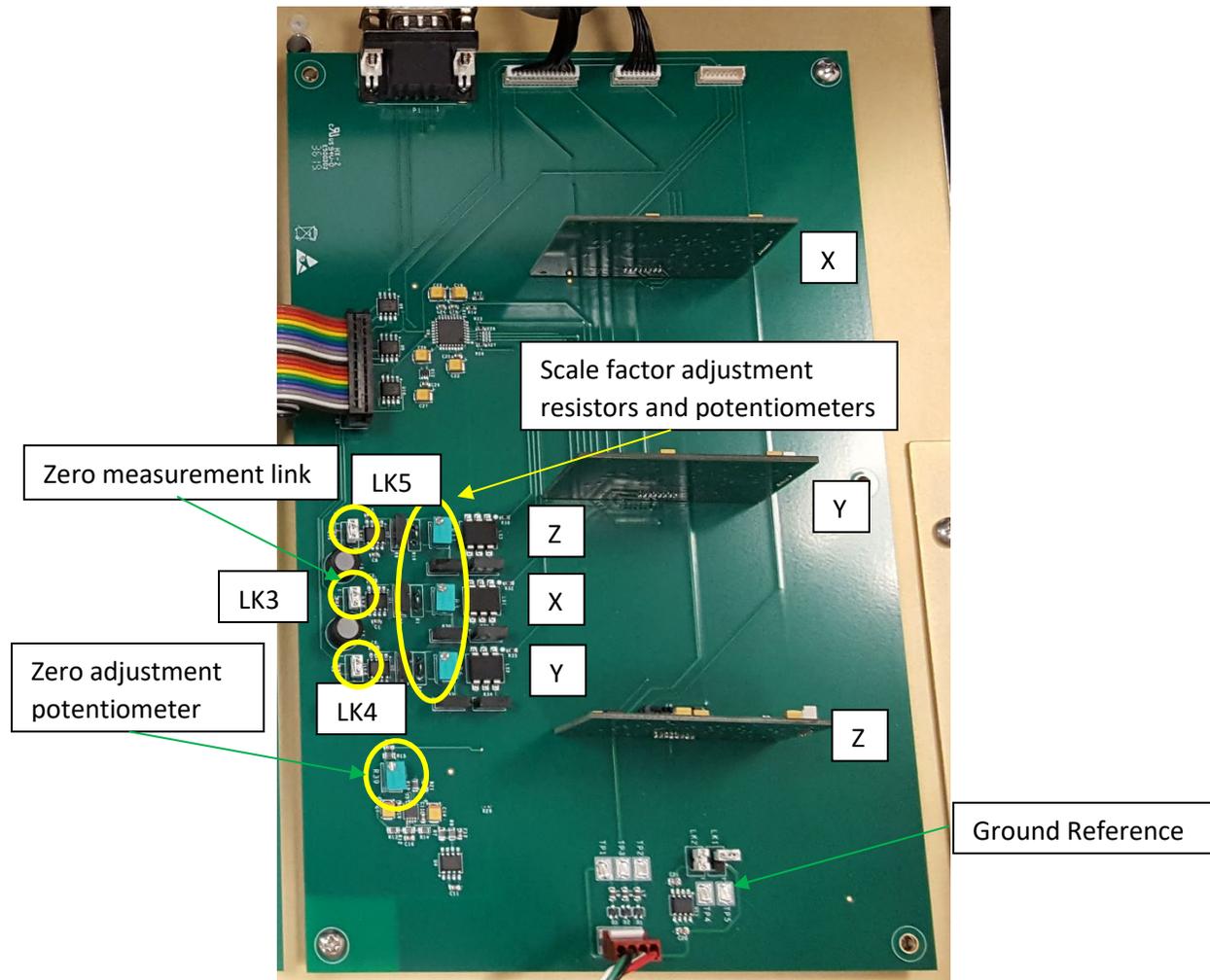


Figure 6-3 Field Controller PCB

### 6.2.1.1 Zero Correction

The Zero measurement links need to be installed prior to making this adjustment. After the adjustment remove the Zero measurement links.

To adjust the zero offset of the Field Controller:

1. Connect LK3, LK4 and LK5.
2. Connect a high resolution (6 digits or more) Multimeter between the Zero measurement link and the Ground Reference point.
3. Turn on the CCM3 and wait 30 seconds.
4. Start the *SSMMF Front Panel* program.
5. Click on the **Connect** icon or **System->Connect** menu item to connect to the HCS01.
6. Enter 200000 into the **Field Magnitude** control and note the Multimeter measurement.
7. Enter -200000 into the **Field Magnitude** control and note the Multimeter measurement.

8. Subtract the two measurements and divide the results by 2.
9. Adjust the Zero adjustment potentiometer until the Multimeter reading magnitude agrees with the calculation in step 7.
10. Enter 200000 into the Field Magnitude control and verify that the Multimeter reading magnitude is within 100  $\mu\text{V}$  of the value calculated in step 7.
11. Repeat this process until the -200000 and the 200000 Multimeter magnitude readings agree within 100  $\mu\text{V}$ .
12. Disconnect LK3, LK4 and LK5.

This completes the zero-adjustment process.

### 6.2.1.2 Scale Factor Adjustment

The zero adjustment (Section 6.2.1.1) must be performed before adjusting the scale factor. The following procedure provides a coarse adjustment of the scale factor. The tuning function in the SSMMF Front Panel program is used to generate a final adjustment. The following procedure assumes that the CCM-3 and RM100 have been powered on for a minimum of 30 minutes and the RM100 is in the Auto measurement mode.

To adjust the scale factor:

1. Verify that LK3, LK4 and LK5 are not connected.
2. Place the HCS01 calibration fixture on the calibration podium in the middle of the HCS01 coil assembly.
3. Mount the RM100 sensor on the calibration podium and align it with the coil assembly X axis.
4. Start the *HCS01 Front Panel* program.
5. Perform the **PREPARATION PROCEEDURE** in Section 6.3.1.1.
6. Adjust the zero offset in the center of the coil system to within 1 nT.
7. Attach a resistor substitute box to R1 on the CCM-3 field controller PCB.
8. Apply an 80,000 nT field and note the field measured by the RM100.
9. Adjust R3 to one extreme and note the measured field.
10. Adjust R3 to the other extreme and note the measured field.
11. Compute the average valued of the two measurements and adjust R3 until the measured field is within 10 nT of the average value.
12. Adjust the resistor substitute box resistance until the measured field is within 100 nT.
13. Install a resistor into R1 that is as close to the substitution box resistance as possible.
14. Adjust the R3 until the measured field is 80,000 nT  $\pm$  5nT.
15. Apply a -80,000 nT field and verify that the measured field is -80,000 nT  $\pm$  5 nT.
16. Rotate the calibration fixture so the RM100 sensor is aligned with the Y axis of the coil assembly.
17. Repeat steps 6 through 15 except change R1 to R4 and R3 to R6.
18. Rotate the RM100 sensor on the calibration fixture so it is along the Z axis and pointing vertically down (cable end of the sensor is pointing up).
19. Repeat steps 6 through 15 except change R1 to R10 and R3 to R11. Since the sensor is pointing down the measured values will have the opposite polarity than the applied fields.

This completes the Closed Loop scale factor adjustments. Go to section 6.3 to complete the Closed Loop tuning and calibration of the HCS01.

### 6.2.2 Open Loop Scale Factor Adjustment and Ambient Field Nullification

The procedures in Section 6.2.1 must be performed before executing the following procedure.

When the system is initially installed the nominal local ambient field must be nulled by selecting and installing resistors on the BOBIF DUAL boards attached to the back of the BOPs (see Fig. 6-4). Resistors R6 and R8 are selected to do a coarse cancellation of the local ambient field. Trim potentiometer R7 is used to improve the coarse cancellation. The resistor values do depend on the ambient field at the time this procedure is executed. Since the ambient field will change throughout the day the field inside the coil assembly will also change. In Open Loop the changes in ambient field are not compensated.

The scale factor of the Open Loop operation must also be adjusted. R9 and R10 are selected to set the coarse open loop scale factor. R2 is used to trim the scale factor. The final scale factor correction is done using the *HCS01 Front Panel* software program.

The following procedures are performed on each coil system axis.

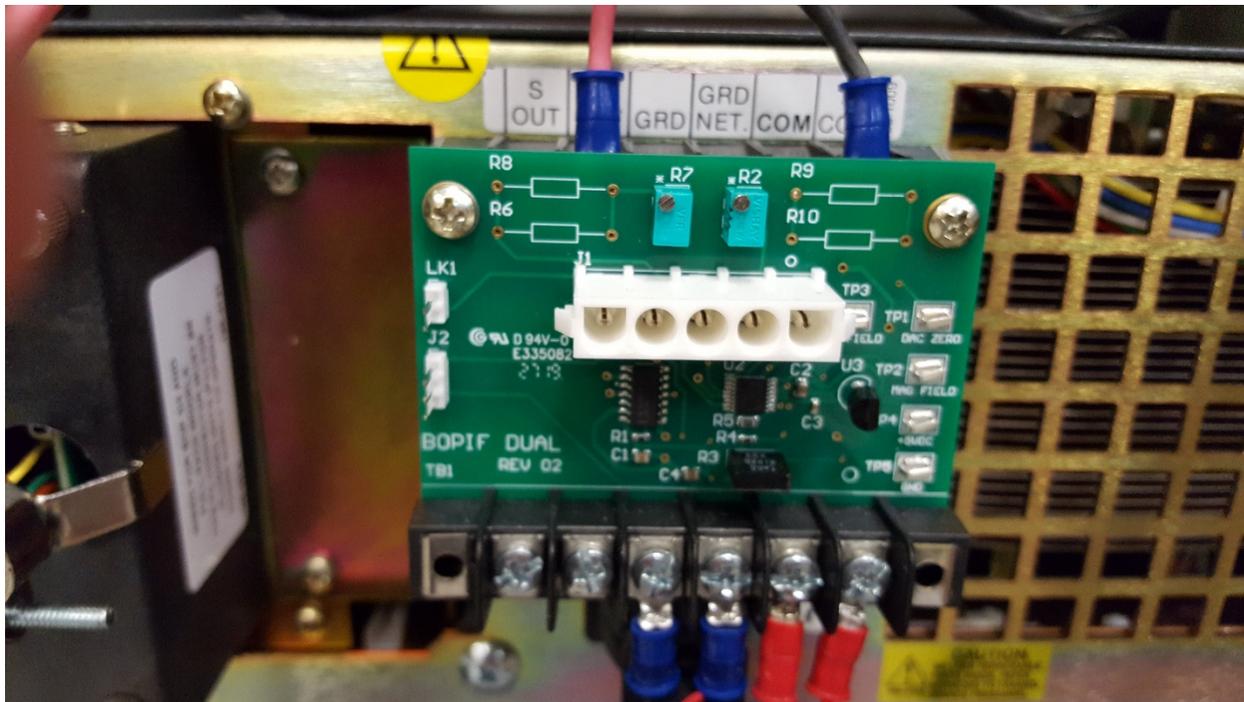


Figure 6-4 BOBIF board attached to back of BOP

Figure 6-5 is a schematic of the BOBIF DUAL.

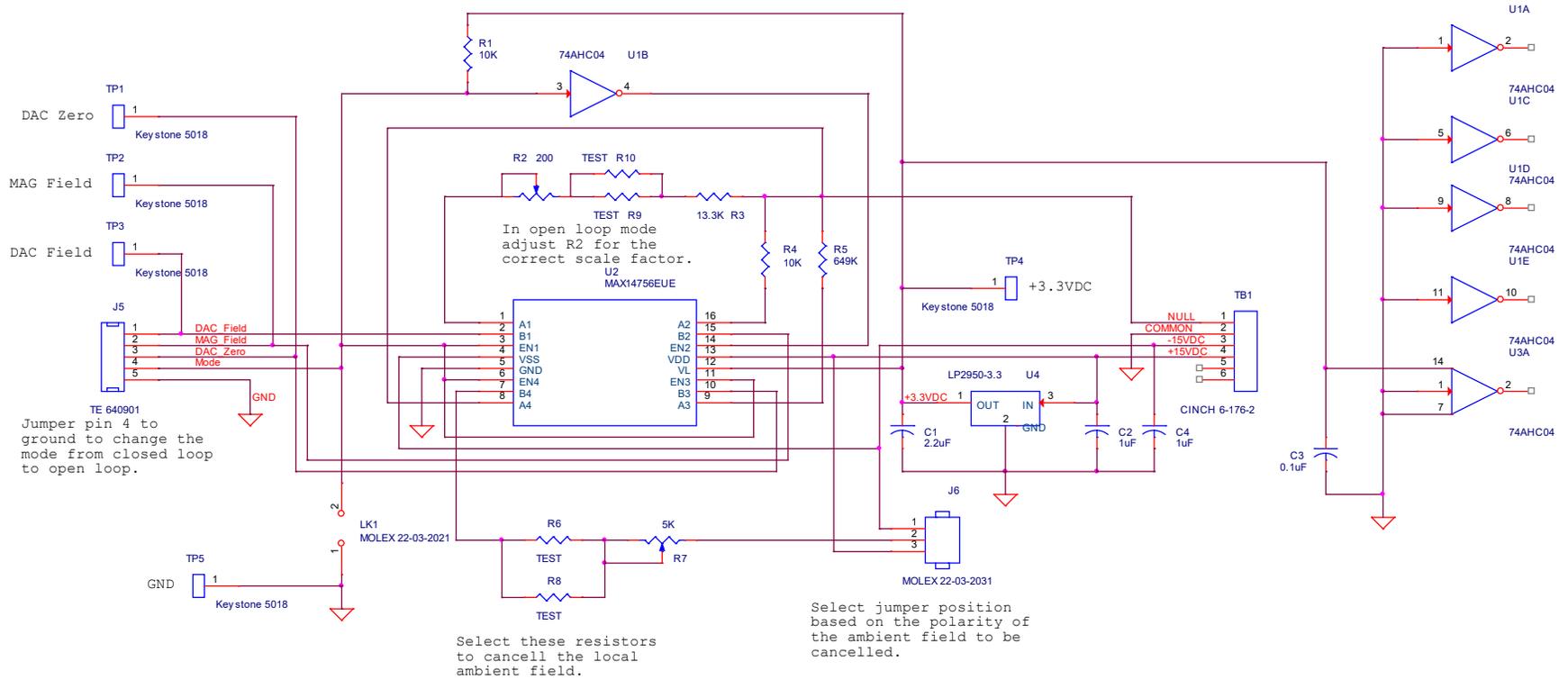


Figure 6-5 BOPIF DUAL schematic

### 6.2.2.1 Ambient Field Nullification

The nullification of the local ambient field must be performed before adjusting the scale factor. To perform this task, mount an FVM400 on the HCS01 calibration fixture and mount the calibration fixture on the podium as shown in Fig. 6-6. The X, Y and Z axes of the FVM400 must be aligned with the X, Y and Z axes of the coil assembly.

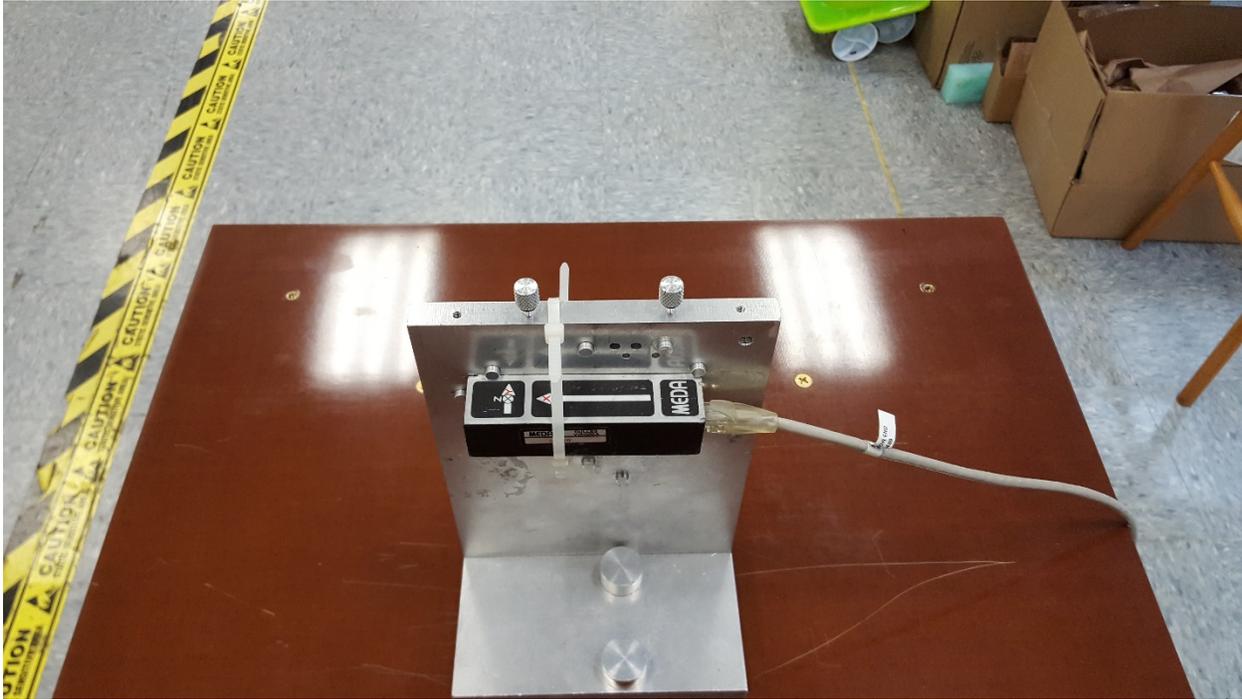


Figure 6-6 FVM400 sensor mounted to the HCS01 calibration fixture installed on the podium

To nullify the local ambient field along the X axis of the 4-m coil assembly:

1. Remove any jumper on J6 of the X, Y and Z axis BOPIF DUAL PCBs.
2. Turn on the FVM400 and note the X axis field reading.
3. Set a resistor substitution box to 50 K $\Omega$ .
4. Connect the resistor substitution box to R6 of the X Axis BOPIF DUAL PCB.
5. Connect a jumper between pin 1 and 2 of J6 of the BOPIF DUAL PCB and note the change in the FVM400 X axis reading.
6. If the X axis field magnitude decreased continue to step 7 otherwise remove the jumper between pin 1 and 2 of J6 and place it between 2 and 3 of J6.
7. Adjust trim pot R7 until it is at one extreme and note the X axis reading on the FVM400.
8. Adjust trim pot R7 until it is at the other extreme and note the X axis reading on the FVM400.
9. Compute the average of the two readings and adjust R7 until the FVM400 reading is equal to the average within 10 nT.
10. Adjust the resistance of the substitution box until the FVM400 X axis reading is 0 nT  $\pm$  100 nT.
11. Install a resistor in R6 which is as close as possible to the resistance of the substitution box.

12. If the FVM400 X axis reading is outside the range of  $0 \text{ nT} \pm 500 \text{ nT}$  connect the resistor substitution box to R8 and adjust the resistance until the FVM400 X axis reading is  $0 \text{ nT} \pm 100 \text{ nT}$  otherwise continue to step 13.
13. Adjust R5 until the FVM400 X axis reading is  $0 \text{ nT} \pm 10 \text{ nT}$ .

This completes the nullification of the 4-m coil assembly X axis ambient field. Repeat the above procedure for the Y and Z axis substituting Y and Z in the procedure.

### 6.2.2.2 Scale Factor Adjustment

This procedure sets the nominal scale factors of the HCS01 in the Open Loop mode. To perform this task mount the RM100 sensor on the HCS01 calibration fixture (see Fig. 6-7) and start the *HCS01 Front Panel* program.

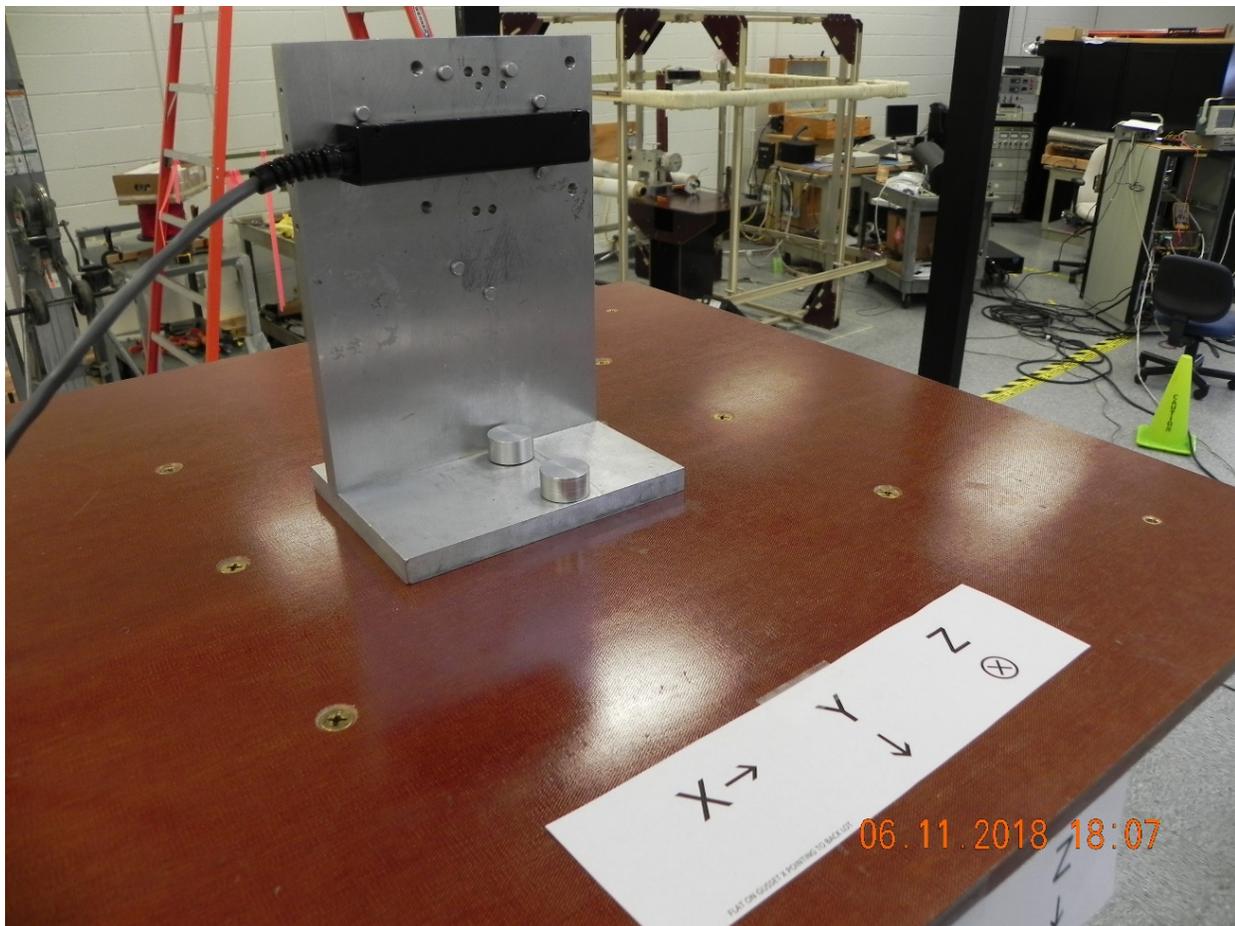


Figure 6-7 RM100 sensor mounted to the HCS01 calibration fixture mounted to the podium

To adjust the X axis Open Loop mode scale factor:

1. Verify that LK3, LK4 and LK5 are not connected.

2. Rotate the HCS01 calibration fixture so the RM100 sensor is aligned with the 4-m coil assembly X axis.
3. Set the RM100 measurement mode to Auto by pressing the Shift key followed by the Auto key.
4. Set the *HCS01 Front Panel* X, Y and Z axes **Field Magnitudes** to 0 nT.
5. Use the *HCS01 Front Panel* X **Zero Adjust** control to adjust the RM100 reading to 0 nT  $\pm$  1 nT.
6. Attach a resistor substitution box to R9 of the X BOPIF DUAL PCB and set it to 0 $\Omega$ .
7. Apply a +80,000 nT field to the X axis using the *HCS01 Front Panel* X **Field Magnitude** control.
8. Adjust trim pot R2 to one extreme and note the RM100 reading.
9. Adjust the trip pot R2 to the other extreme and note the RM100 reading.
10. Compute the average reading and adjust R2 so the reading is equal to the average reading within 50 nT.
11. Adjust the resistor substitution box resistance until the RM100 reading is +80,000 nT  $\pm$  100 nT.
12. Install a resistor into R9 that is as close as possible to the resistor substitute box value.
13. If the RM100 reading after installing the resistor is equal to or less than +80,000 nT  $\pm$  100 nT go to step 14 else attach the substitute resistor box to R10 and adjust its resistance until the RM100 reading is less than +80,000 nT  $\pm$  100 nT and install the closest resistance to the resistor substitute box in R10.
14. Adjust R2 until the RM100 reading is +80,000 nT  $\pm$  10 nT.

This completed the adjustment of the X axis Open Loop scale factor. Repeat the above procedure for the Y and Z axes substituting Y or Z for X in the procedure.

This completes the Open Loop scale factor adjustments. The final adjustment is done using the procedures described in Section 6.3.

## 6.3 TUNING AND CALIBRATION

When the HCS01 is first delivered it has been partially calibrated and performance has been verified at the factory. When the system is first installed on-site its calibration needs to be adjusted for the on-site location. Adjustment involves a series of steps that are used to calibrate both the Open Loop and Closed Loop performance and to initially zero the system at the geometric center of the test volume. The following equipment are needed to perform the calibration and zero adjustments.

1. HCS01 calibration fixture (not included).
2. RM100 single axis Reference Magnetometer (not included).
3. Keithley 6221 current source (not included).
4. *HCS01 Front Panel* software (included).

The *HCS01 Front Panel* program includes functions for performing all of the required HCS01 calibrations.

### 6.3.1 Initial On-Site Calibration

After the HCS01 has been installed on-site it needs to be recalibrated. This requires the following steps.

1. Mount the HCS01 calibration fixture on the podium and the RM100 sensor to the calibration fixture.
2. Set the operating mode to **Closed Loop**.
3. Tune each axis to measure its scale factor and alignment coefficients.
4. Save the new calibration coefficients to the CCM-3 controller.
5. Verify the calibration of each axis.
6. Set the operating mode to **Open Loop**.
7. Adjust the **Open Loop** ambient field compensation resistors to perform a coarse null of the local ambient field.
8. Tune each axis to measure its scale factor and alignment coefficients.
9. Save the new calibration coefficients to the CCM-3 controller.
10. Verify the calibration of each axis.

The following procedures assume that the adjustments described in Section 6.2 have been performed.

#### 6.3.1.1 Tuning

The tuning procedure measures the scale factor (Volts/nT) and the three alignment coefficients of the axis under test. The *SSMMF Front Panel* program performs this task under user control. The program applies a field in one axis at a time and measures the actual field applied. The measured fields are used to compute the scale factor and alignment coefficients. For example, the X-axis scale factor is computed using the following equation:

$$SF_x = (H_x^0 - H_x^{180}) / (2 \cdot H_a)$$

$H_x^0$  = the measured field for an applied field in the plus X direction.

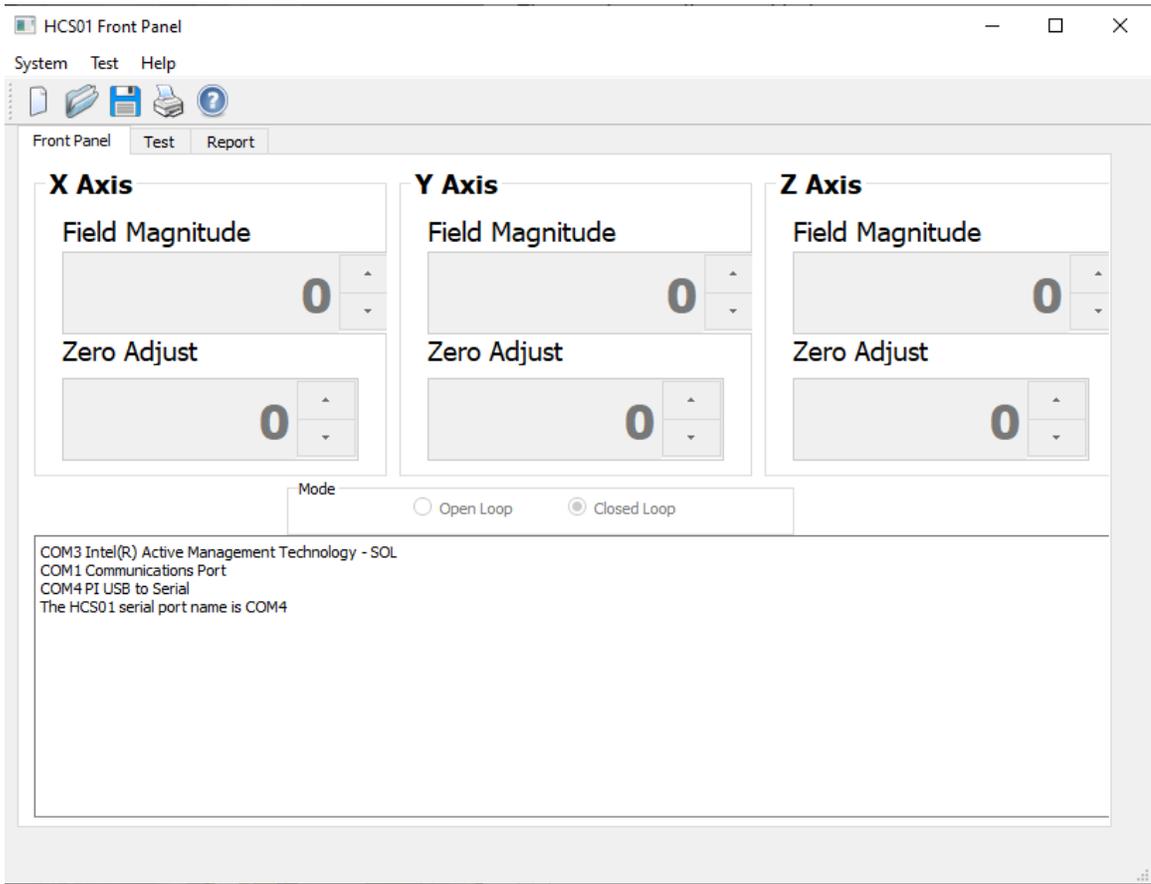
$H_x^{180}$  = the measured field for an applied field in the minus X direction.

$H_a$  = the magnitude of the applied field along the X axis.

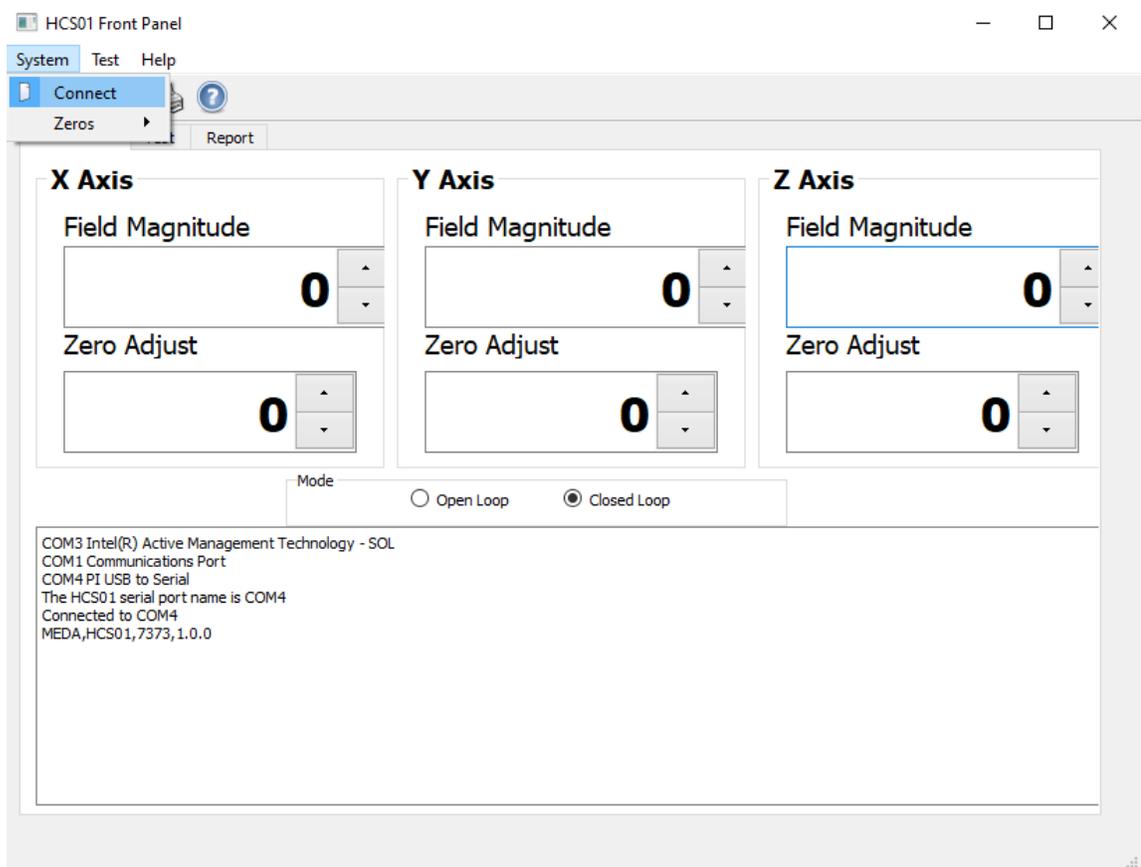
The ideal scale factor is 1.0000. The actual scale factors should be between 1.0005 and 0.9995. The alignment coefficients are computed from the measured responses along the axis under test to cross fields. See Appendix A for an explanation of how these coefficients are computed.

#### PREPARATION PROCEDURE:

1. Turn on the system using the procedure described in Section 3.1.
2. Start the *HCS01 Front Panel* program. The following screen will appear. The controls will be disabled until connected to the CCM-3 field controller.

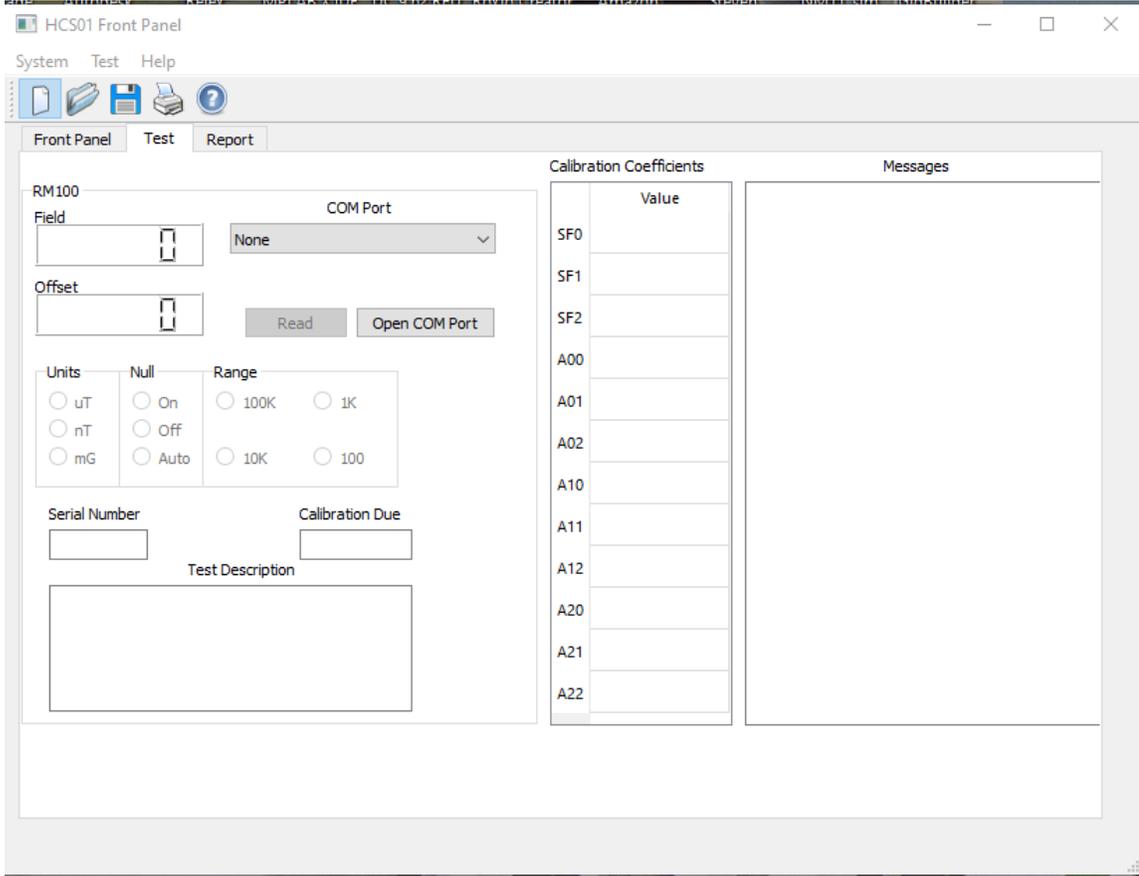


3. Click on the **System** menu and then on the **Connect to HCS01** selection (see figure below).

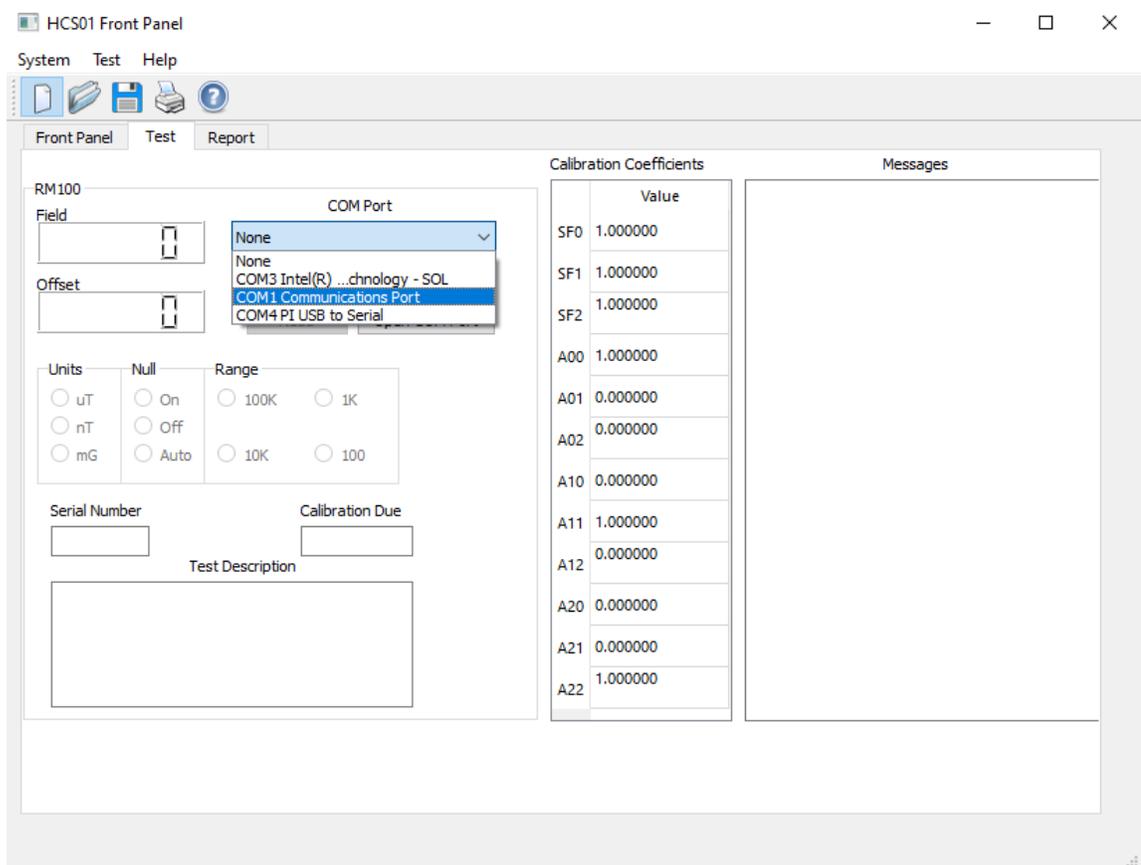


4. Assuming everything is connected properly this will connect the *HCS01 Front Panel* program to the CCM-3 field controller. If there is a problem connecting, make sure the CCM-3 is connected to the PC through a USB port and the CCM-3 is powered on.

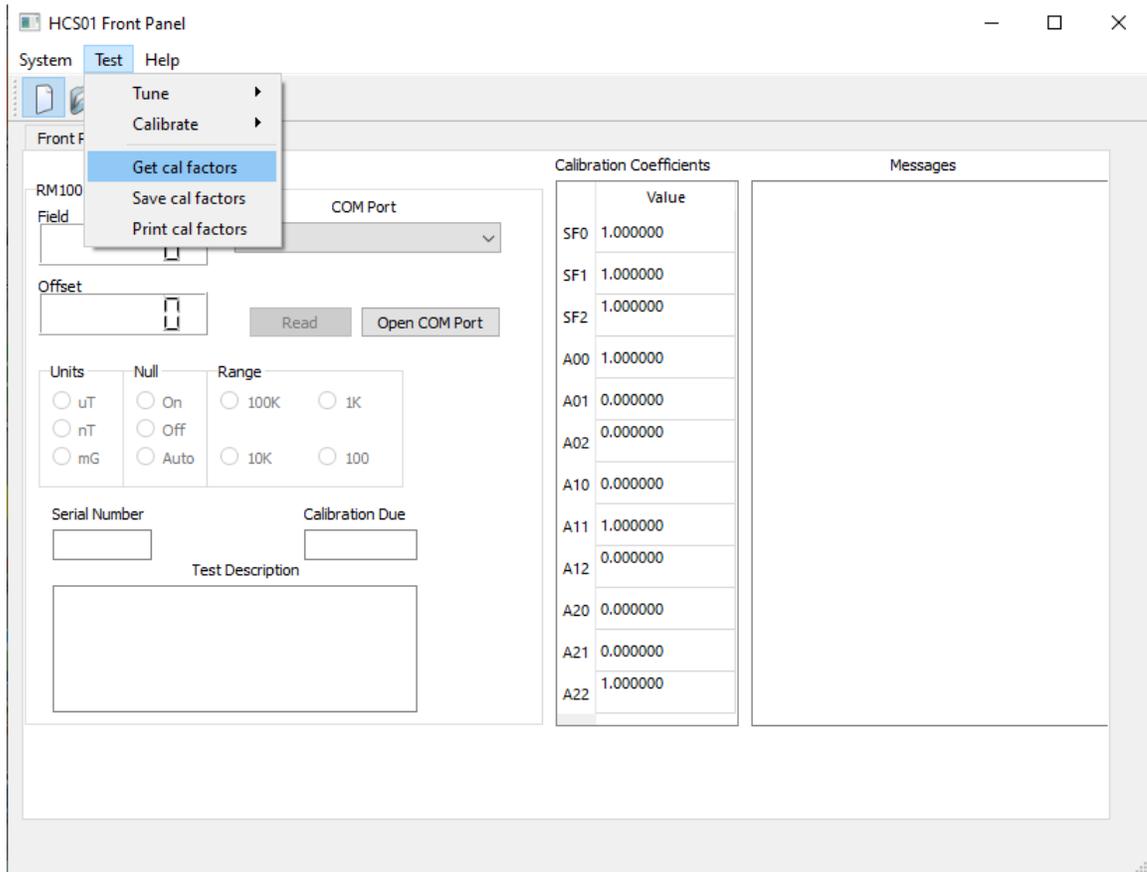
- 5. Click on the **Test** tab. The following screen will appear.



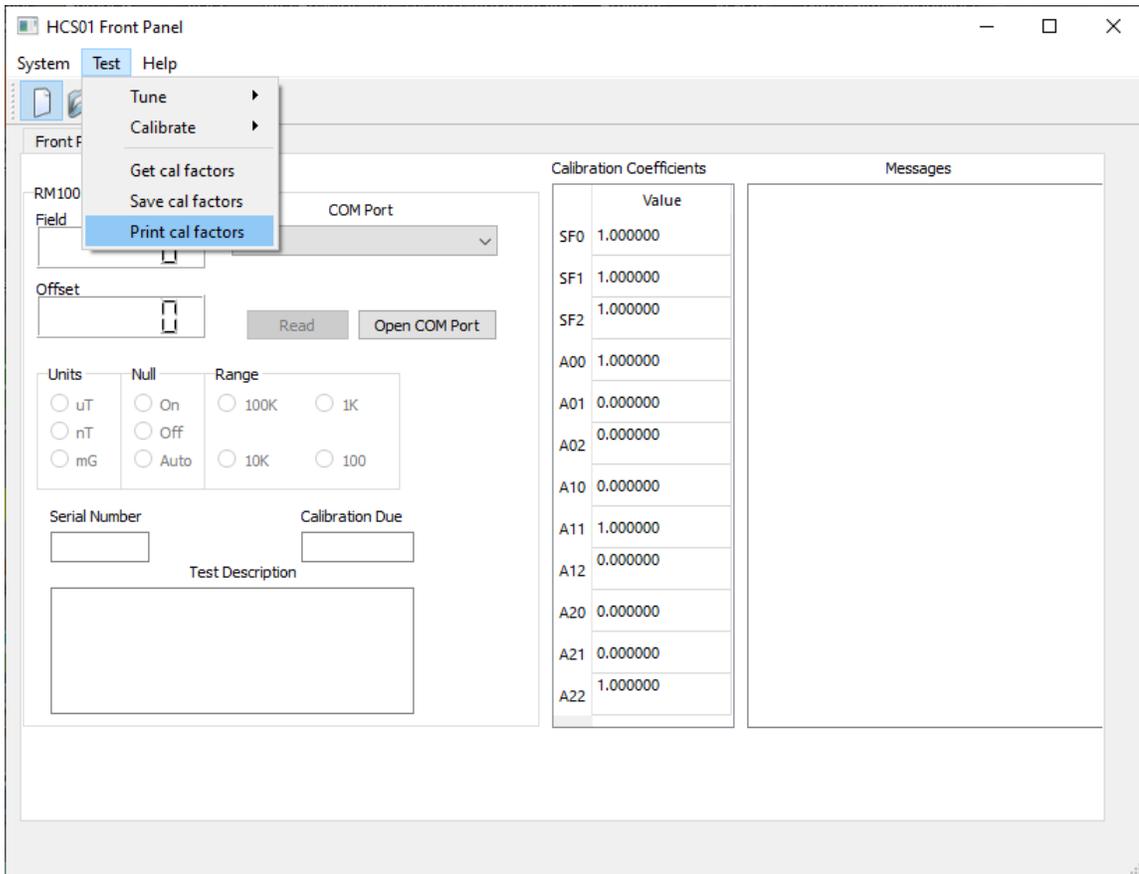
- Click on the down arrow to the right of the **COM Port** selection control and select the COM port that is connected to the RM100.



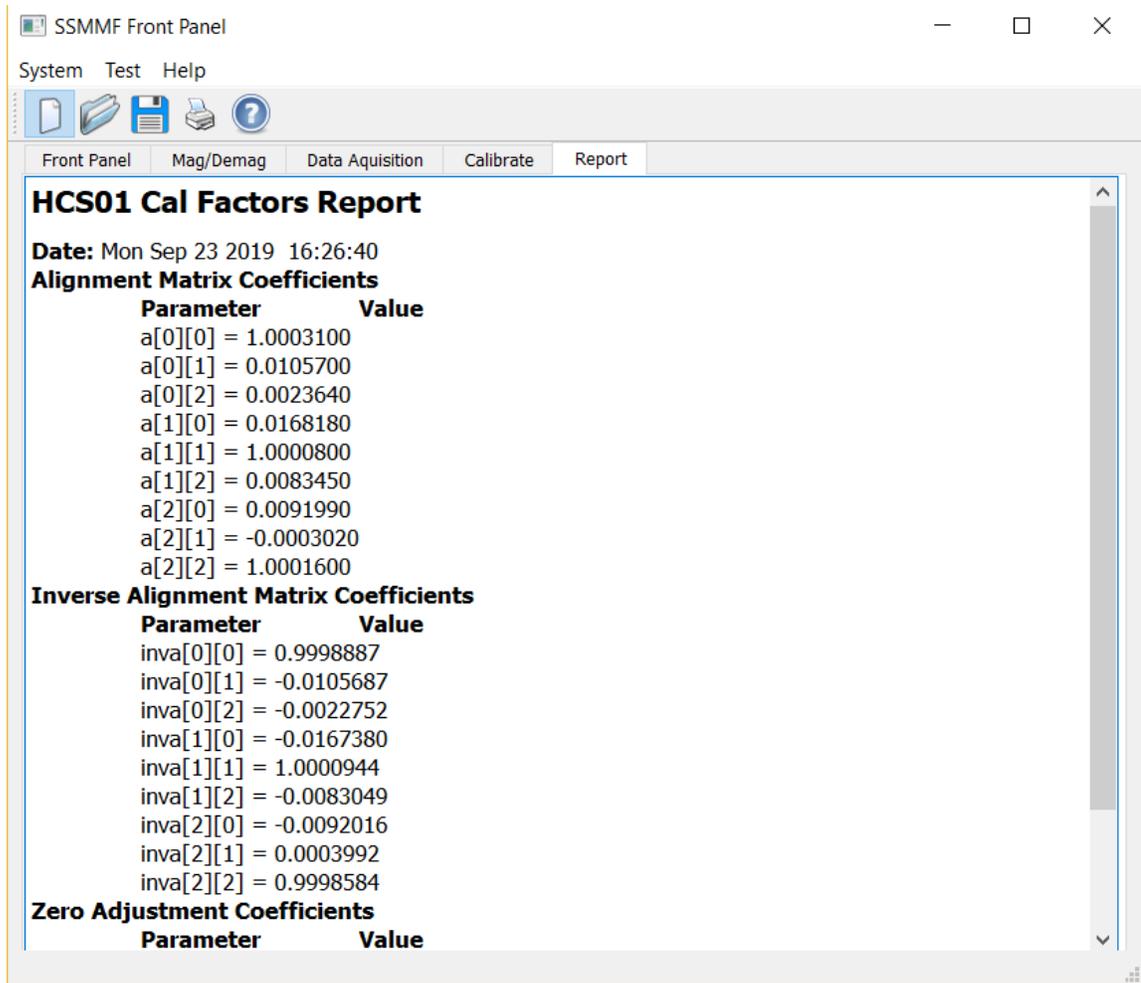
- When the RM100 connects the RM100 controls will be enabled. The RM100 must be connected in order to calibrate the SSMMF coil system.
- Click on the **Test->Get cal factors** menu selection. This will load in the calibration factors currently stored in the CCM-3 Field Controller and display them in the HCS01 Calibration Coefficient table.



9. Click on the **Test->Print cal factors** menu selection to print the current calibration factors.



10. The following Cal Factors report screen will be displayed.



11. Click on the Save icon to save the data to a file or click on the Print icon to print a report.
12. Click on the Calibrate tab. In the HCS01 Calibration Coefficient table enter the ideal values for the calibration coefficients. The ideal values are
  - > SF0, SF1 and SF2 = 1.0
  - > A00, A11 and A22 = 1.0
  - > All other values = 0.0
13. Click on the **Test->Save cal factors** menu selection to save the ideal calibration factors to the CCM-3 field controller.
14. Exit the *HCS01 Front Panel* program.
15. Power cycle the CCM-3 and wait 30 seconds for it to stabilize.

16. Start the *HCS01 Front Panel* program, connect to the CCM-3 and navigate to the Calibrate tab.
17. Click on the **Test->Get cal factors** menu selection to read in the calibration factors stored in the CCM-3 Field Controller. Verify that they are the ideal values entered in step 12. If they are not correct then correct them and repeat steps 13 through 17.

At this point the HCS01 is ready for tuning.

#### **TUNING PROCEEDURE:**

1. Click on the **Test->Tune HCS01->X Axis** menu item.
2. Follow the instructions displayed on the screen.
3. Repeat steps 1 and 2 for the Y axis and the Z axis.
4. At the completion of these steps the HCS01 Calibration Coefficients table will be filled with the new calibration coefficients. Click on the **Test->Print cal factors** menu item to display a report and then print the report.
5. Click on the **Test->Save cal factors** menu item to save the new calibration coefficients to the CCM-3 Field Controller.
6. Exit the *HCS01 Front Panel* program.
7. Power cycle the CCM-3 and wait 30 seconds for the CCM-3 to stabilize.
8. Start the *SSMMF Front Panel* program, connect to the CCM-3 and navigate to the Calibrate tab.
9. Click on the **Test->Get cal factors** menu item.
10. Compare the data in the HCS01 Calibration Factors table to the report printed in step 4 to verify that the CCM-3 Field Controller is using the new calibration coefficients.

This completes the tuning procedure. The HCS01 is now ready to be calibrated.

#### **6.3.1.2 Calibration Procedure**

Because of the RM100 measurement range limitation the HCS01 must be calibrated using two different procedures: One for the 100,000 nT range and a second one for the 100,000 nT to 200,000 nT range.

##### **6.3.1.2.1 RANGE 1 (100,000 nT):**

The test program described in this section applies the following fields to the axis under test and measures the response of the system:

{99950, 90000, 80000, 70000, 60000, 50000, 40000, 30000, 20000, 10000,  
-10000, -20000, -30000, -40000, -50000, -60000, -70000, -80000, -90000, -99950} nT.

To determine the alignment of the axis under test fields are applied by the other axes. Assuming the X axis is under test then the following cross fields will be applied and the response along the X axis measured:

Y – Axis  $\pm 80,000$  nT.

Y – Axis  $\pm 80,000$  nT.

Only one axis is tested at a time in any desired sequence.

1. Click on the **Test->Calibrate HCS01->X Axis** menu item.
2. Follow the instructions displayed on the screen.
3. When the test report for the X axis is displayed in the report tab save the report to a file by clicking on the Save icon.
4. Repeat steps 1 to 3 for the Y axis and the Z axis.

Below is an example of a typical test report.

## HCS01 Calibration Report

HCS01 SN: 8000

Test Description: After alignment correction

Date: Mon May 20 2019 12:14:17

RM100 SN: 6946 Calibration Due: 03/11/2020

### Y - AXIS

| Applied (nT) | Measured (nT) | Tolerance |         |
|--------------|---------------|-----------|---------|
| 99950        | 99954         | 99900     | 100000  |
| 90000        | 90003         | 89955     | 90045   |
| 80000        | 80001         | 79960     | 80040   |
| 70000        | 70002         | 69965     | 70035   |
| 60000        | 60002         | 59970     | 60030   |
| 50000        | 50002         | 49975     | 50025   |
| 40000        | 40003         | 39980     | 40020   |
| 30000        | 30002         | 29985     | 30015   |
| 20000        | 20003         | 19990     | 20010   |
| 10000        | 10000         | 9995      | 10005   |
| -10000       | -9997         | -9995     | -10005  |
| -20000       | -19996        | -19990    | -20010  |
| -30000       | -29996        | -29985    | -30015  |
| -40000       | -39996        | -39980    | -40020  |
| -50000       | -49997        | -49975    | -50025  |
| -60000       | -59997        | -59970    | -60030  |
| -70000       | -69998        | -69965    | -70035  |
| -80000       | -79999        | -79960    | -80040  |
| -90000       | -90000        | -89955    | -90045  |
| -99950       | -99953        | -99900    | -100000 |

Y->X Angle: 0.01 Degrees

Y->Z Angle: -0.00 Degrees

Performed by: \_\_\_\_\_ Reviewed by: \_\_\_\_\_ Date: \_\_\_\_\_

*Figure 6-8 Example Closed Loop calibration report*

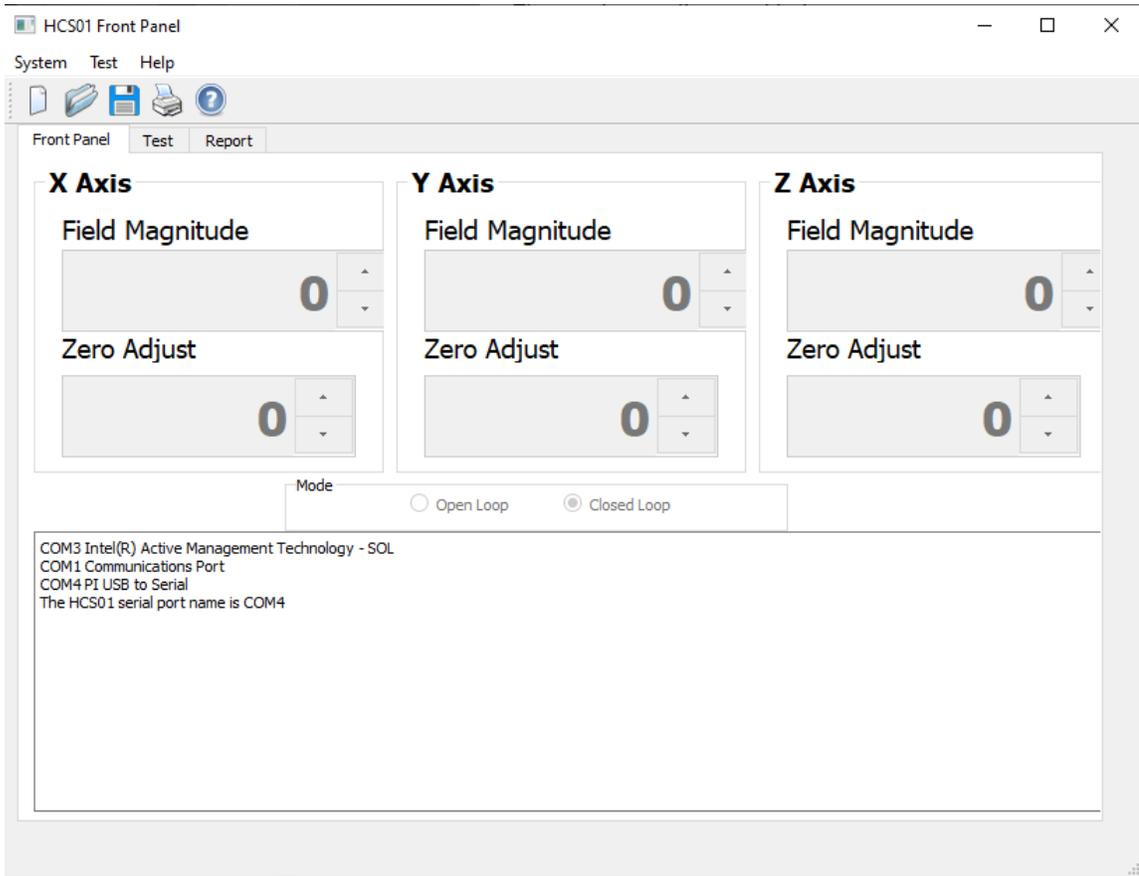
This completes the Range 1 Accuracy and Axis Alignment test of the HCS01 coil system. All measured field values shall be within the tolerance range listed in the report.

#### 6.3.1.2.2 RANGE 2 (200,000 nT):

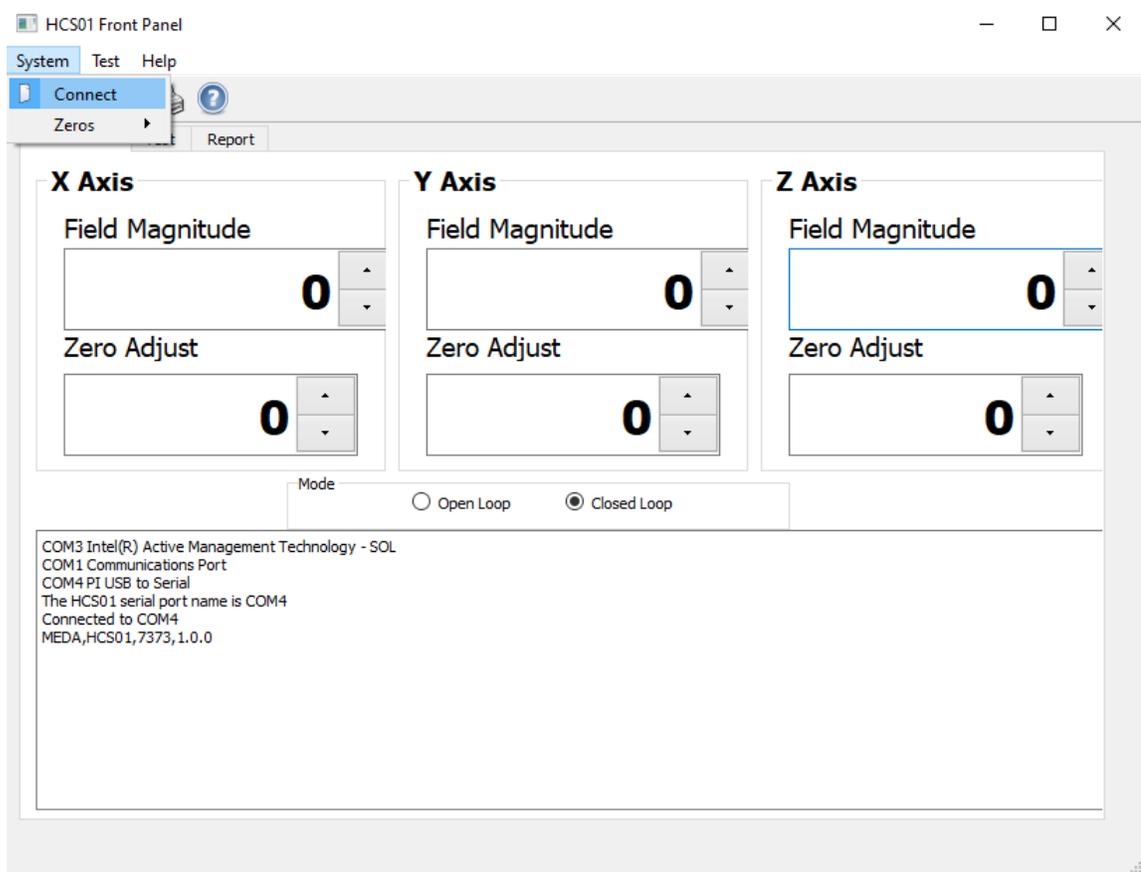
The RM100 measurement range is limited to  $\pm 100,000$  nT. In order to calibrate the SSMMF coil system for fields greater than 100,000 nT a bias field must be applied to the RM100 using an external field source. The data is recorded by hand as described in the following procedure.

1. Apply power to the CCM-3 and wait 30 seconds for the CCM3 to initialize.

2. Start the *HCS01 Front Panel* program. The following screen will appear. The controls will be disabled until connected to the CCM-3 field controller.



- Click on the **System->Connect to HCS01** menu item. The six controls will change from dimmed to white and display the CCM-3 field controller values.



- Place the RM100 in the HCS01 test fixture solenoid and attach the solenoid to the HCS01 test fixture.
- Place the HCS01 test fixture in the HCS01 coil system and align the RM100 sensor along the X axis.
- Connect a Keithley 6221 current source to the test fixture solenoid.
- Use the X Axis **Zero Adjust** coils to adjust the field until the RM100 reading is  $0 \pm 1$  nT.
- Apply a +90,000 nT field using the X Axis **Field Magnitude** control.
- Adjust the current source to null the applied field to within  $0 \pm 10$  nT.
- Apply a 0 nT field using the **X Axis Field Magnitude** control.
- Record the RM100 reading on Data Sheet 2.

12. Apply a +110,000 nT field using the X Axis **Field Magnitude** control.
13. Record the RM100 measurement on Data Sheet.
14. Apply a 0 nT field using the X Axis **Field Magnitude** control.
15. Record the RM100 reading on Data Sheet.
16. Repeat these steps for all of the fields listed on Data Sheet.
17. Repeat the above steps for the negative applied fields on Data Sheet.
18. Repeat the above steps for the Y and Z axis.

Perform the computations specified on Data Sheet.

The following is an example of the 200,000 nT Data Sheet

## SSMMF COIL SYSTEM 2000 mG RANGE DATA SHEET

Configuration: \_\_\_\_\_

SN: \_\_\_\_\_

Date: \_\_\_\_\_

### X AXIS

| Applied Field (nT) | Zero (nT) | Reading (nT) | Zero + Reading | TOLERANCE (nT)     |
|--------------------|-----------|--------------|----------------|--------------------|
| 110,000            |           |              |                | 109,945 to 110,055 |
| 120,000            |           |              |                | 119,940 to 120,060 |
| 130,000            |           |              |                | 129,935 to 130,065 |
| 140,000            |           |              |                | 139,930 to 140,070 |
| 150,000            |           |              |                | 149,925 to 150,075 |
| 160,000            |           |              |                | 159,920 to 160,080 |
| 170,000            |           |              |                | 169,915 to 170,086 |
| 180,000            |           |              |                | 179,910 to 180,090 |
| 190,000            |           |              |                | 189,905 to 190,095 |
| 198,000            |           |              |                | 197,101 to 198,099 |

Test Performed By: \_\_\_\_\_ Date: \_\_\_\_\_

Checked By: \_\_\_\_\_ Date: \_\_\_\_\_

## SSMMF COIL SYSTEM 2000 mG RANGE DATA SHEET

Configuration: \_\_\_\_\_

SN: \_\_\_\_\_

Date: \_\_\_\_\_

### X AXIS

| Applied Field (nT) | Zero (nT) | Reading (nT) | Zero + Reading | TOLERANCE (nT)       |
|--------------------|-----------|--------------|----------------|----------------------|
| -110,000           |           |              |                | -109,945 to -110,055 |
| -120,000           |           |              |                | -119,940 to -120,060 |
| -130,000           |           |              |                | -129,935 to -130,065 |
| -140,000           |           |              |                | -139,930 to -140,070 |
| -150,000           |           |              |                | -149,925 to -150,075 |
| -160,000           |           |              |                | -159,920 to -160,080 |
| -170,000           |           |              |                | -169,915 to -170,086 |
| -180,000           |           |              |                | -179,910 to -180,090 |
| -190,000           |           |              |                | -189,905 to -190,095 |
| -198000            |           |              |                | -197,101 to -198,099 |

Test Performed By: \_\_\_\_\_ Date: \_\_\_\_\_

Checked By: \_\_\_\_\_ Date: \_\_\_\_\_

## 6.4 TROUBLESHOOTING

The HCS01 is a complex feedback control system. Personnel assigned to troubleshoot and repair the HCS01 should have a thorough understanding of electronic feedback systems and how the HCS01 works. Troubleshooting should be limited to isolating the module that is causing the failure. The module manufacturer is the best one to perform a repair of the module.

The BOP manual does provide detailed information that may be used to perform repairs. This is a complex piece of equipment and MEDA recommends that, unless there are trained personnel on site who are familiar with this equipment, the BOP should be returned to KEPCO for repair.

The same can be said for the CCM-3 coil control magnetometer. This unit should be returned to MEDA for repair.

Unless the failure is catastrophic, such as a BOP voltage or current overload, it may be difficult to detect a system failure. Periodic health tests, using a high-quality magnetometer such as the RM100 or FVM-400 manufactured by MEDA, are the best way to detect system failures. The frequency of the health tests must be determined by the test facility needs. Unexpected behavior of a device under test should also alert test personnel that an HCS01 failure has occurred.

Once a failure has been detected, a magnetometer is usually needed to troubleshoot the system. The troubleshooting procedures described in the following sections assume that a magnetometer is available along with a digital Multimeter.

The following table lists the most common observed failure effects, possible causes of the failure and remedies. The failures observed assume that the HCS01 was working properly before observing the failure and that no changes were made to the HCS01 prior to the failure. If any module is replaced, the system must be readjusted, retuned and recalibrated.

Table 6-1 Failure Modes, effects and remedies

| Effect | Observed Effect  | Possible Causes  | Remedies   |
|--------|--|--|--|
| 1      | One or more axes of the local ambient field are not nulled after the system is turned on.    | <ul style="list-style-type: none"> <li>• BOP internal failure</li> <li>• BOP Mode switch set to Voltage</li> <li>• BOP program card failure</li> <li>• CCM3 analog magnetometer failure</li> <li>• BOPIF DUAL PCB failure</li> <li>• Faulty cable connection between the SSMMF rack and the 4-m coil assembly (most likely failure)</li> </ul> | <ul style="list-style-type: none"> <li>• Replace the BOP and return to KEPCO for repair</li> <li>• Change mode switch to Current</li> <li>• Replace BOP program card</li> <li>• Return magnetometer to MEDA for repair</li> <li>• Replace the BOPIF DUAL PCB</li> <li>• Repair the connection</li> </ul>                 |
| 2      | A BOP output voltage is at an extreme, the output current is zero and the fault light is on. | <ul style="list-style-type: none"> <li>• BOP internal failure</li> <li>• Cable between the SSMMF rack and the 4-m coil assembly is open (most likely failure)</li> </ul>   | <ul style="list-style-type: none"> <li>• Replace the BOP and return to KEPCO for repair</li> <li>• Fix the cable connection</li> </ul>   |
| 3      | A BOP output current is at an extreme and the fault light is on                              | <ul style="list-style-type: none"> <li>• BOP internal failure</li> <li>• Cable between the SSMMF rack and the 4-m coil assembly is shorted.</li> <li>• CCM-3 analog magnetometer failure</li> <li>• CCM-3 field controller failure</li> <li>• BOPIF DUAL PCB failure</li> </ul>  | <ul style="list-style-type: none"> <li>• Replace the BOP and return to KEPCO for repair</li> <li>• Fix the cable connection</li> <li>• Return the CCM-3 magnetometer to MEDA for repair</li> <li>• Replace the CCM-3 field controller PCB and return to MEDA for repair</li> <li>• Replace the BOPIF DUAL PCB</li> </ul> |

|   |   |   |   |
|---|---|---|---|
| 4 | Cannot adjust the zero at the center of the 4-m coil assembly   | <ul style="list-style-type: none"> <li>• A ferromagnetic object has been placed near the 4-meter coil assembly and producing a field in the test volume</li> <li>• CCM-3 analog magnetometer failure</li> <li>• CCM-3 field controller failure</li> <li>• BOPIF DUAL PCB failure</li> </ul> | <ul style="list-style-type: none"> <li>• Remove the ferromagnetic object</li> <li>• Return CCM-3 magnetometer to MEDA for repair</li> <li>• Replace the field controller and return to MEDA for repair</li> <li>• Replace the BOPIF DUAL PCB</li> </ul>                 |
| 5 | The <i>HCS01 Front Panel</i> program cannot connect to the CCM-3 Control Magnetometer   | <ul style="list-style-type: none"> <li>• The USB cable between the PC and the CCM-3 is disconnected</li> <li>• The <i>HCS01 Front Panel</i> program was started before the CCM-3 was turned on</li> <li>• The CCM-3 single board computer has failed</li> </ul>                             | <ul style="list-style-type: none"> <li>• Connect the cable</li> <li>• Exit the <i>HCS01 Front Panel</i> program. Power cycle the CCM-3 and wait 30 seconds. Restart the <i>SSMMF Front Panel</i> program.</li> <li>• Replace the CCM-3 Single Board Computer</li> </ul> |
| 6 | The <i>HCS01 Front Panel</i> program connects to the CCM-3 but the field in the test volume does not change when the <i>HCS01 Front Pane Zero Adjust</i> controls are changed | <ul style="list-style-type: none"> <li>• CCM-3 field controller failure</li> <li>• BOPIF DUAL PCB failure (Open Loop mode)</li> </ul>   | <ul style="list-style-type: none"> <li>• Replace the CCM-3 field controller</li> <li>• Replace the BOPIF DUAL PCB</li> </ul>  |
| 9 | The <i>HCS01 Front Panel</i> program connects to the CCM-3 but the field in the test volume does not change   | <ul style="list-style-type: none"> <li>• The cable connecting the CCM-3 magnetometer to the CCM-3 field controller is missing or defective.</li> </ul>  | <ul style="list-style-type: none"> <li>• Connect the cable if missing. If not missing, replace the cable.</li> </ul>  |

|    |   |  |   |
|----|---|--|---|
|    | when the <i>HCS01 Front Pane</i> <b>Field Magnitude</b> controls are changed  | <ul style="list-style-type: none"> <li>• CCM-3 links LK3, LK4 and/or LK5 are connected (Closed Loop)</li> <li>• A CCM-3 field controller 20-bit DAC daughter board has failed. This is normally detected during the HCS01 self-test</li> <li>• A BOPIF DUAL PCB has failed</li> <li>• A CCM-3 sensor calibration winding has shorted.</li> </ul> | <ul style="list-style-type: none"> <li>• Remove any connected links</li> <li>• Replace the DAC daughter board</li> <li>• Replace the BOPIF DUAL PCB</li> <li>• Fix the CCM-3 sensor calibration winding.</li> </ul>   |
| 10 | The <i>HCS01 Front Panel</i> program connects to the CCM-3 but the field in the test volume goes to one extreme or the other when the <i>HCS01 Front Pane</i> <b>Zero Adjust</b> controls are changed                           | <ul style="list-style-type: none"> <li>• Corrupted calibration factors</li> <li>• CCM-3 field controller has failed</li> <li>• CCM-3 Single Board Computer has failed</li> </ul>   | <ul style="list-style-type: none"> <li>• Check the calibration factors and correct using backed up data or retune the HCS01</li> <li>• Replace the CCM-3 field controller</li> <li>• Replace the CCM-3 Single Board Computer</li> </ul>                                 |
| 11 | The <i>HCS01 Front Panel</i> program connects to the CCM-3 but the field in the test volume does not agree with the field value entered into the <i>HCS01 Front Pane</i> <b>Field Magnitude</b> controls within expected limits | <ul style="list-style-type: none"> <li>• CCM-3 field controller has failed</li> <li>• CCM-3 20-bit DAC daughter board has failed</li> <li>• Calibration factors have been corrupted</li> <li>• BOPIF DUAL PCB has failed</li> </ul>  | <ul style="list-style-type: none"> <li>• Replace the CCM-3 controller board</li> <li>• Replace the 20-bit daughter board</li> <li>• Check the calibration factors and correct using backed up data or retune the HCS01</li> <li>• Replace the BOPIF DUAL PCB</li> </ul> |

Some of the more common issues are discussed in the following section to aid in identifying the module that has failed.

#### 6.4.1 Zero Adjustment Out of Range

The field at the center of the coil assembly cannot be set to zero using the *HCS01 Front Panel Zero Adjust* controls. One or more axes could have this problem. This can be caused by one of the following situations:

1. A piece of equipment with ferromagnetic properties was moved into the vicinity of the 4-m coil assembly and is creating a field at the center of the coil assembly.
2. A BOP or CCM-3 failure that causes the feedback loop to open in one or more axes.
3. A failure in the CCM-3 field controller DAC that is used to set the zero.

Before proceeding with troubleshooting verify that a ferromagnetic object has not been placed near the 4-m coil assembly. If such an object is in the vicinity of the 4-m coil system, remove it and try adjusting the zero to see if the problem has gone away.

If the cause was not item 1 above use the following procedure to identify the cause of the problem. An FVM400 or an RM100 mounted to the HCS01 calibration fixture and mounted to the SSMMF calibration podium can be used to perform this test.

1. Disconnect the jumper cable between the CCM-3 Analog Magnetometer and CCM-3 Field Controller.
2. Start the *HCS01 Front Panel* program and make sure the system mode is Closed Loop.
3. Turn the BOPs off and measure the field components at the center of the coil assembly.
4. Turn the X-axis BOP on and measure the X field component at the center. The X field component should be significantly less than the value measured in step 1 (at least 50 times less). If little or no change occurs then the feedback loop is open. In this case go to step 6.
5. Repeat step 4 for the Y and Z axes.
6. If the feedback is open then continue else go to step 8.
7. Replace the BOP and repeat step 3. If the results are the same then the CCM-3 analog magnetometer has failed. If the field is reduced by at least 50 then the BOP has failed.
8. Turn off all the BOPs.
9. Reconnect the jumper between the CCM-3 Analog Magnetometer and the CCM-3 Field Controller PCBs.
10. Turn on the BOPs one at a time.
11. If the problem returns then the CCM-3 Field Controller or one or more of the BOPIF DUAL PCBs has failed.

## 6.4.2 No Response to Zero Field Adjustment

### 6.4.2.1 System in Closed Loop Mode

The HCS01 Front Panel program is communicating with the CCM3 and the field at the center of the coil assembly is within the zero-adjustment range, but nothing happens when the HCS01 Front Panel **Zero Adjust** control is exercised in either Open Loop or Closed Loop mode. Figure 6-8 is the CCM-3 analog magnetometer PCB assembly drawing that will be referred to in the following procedure. The following procedure applies to the X axis.

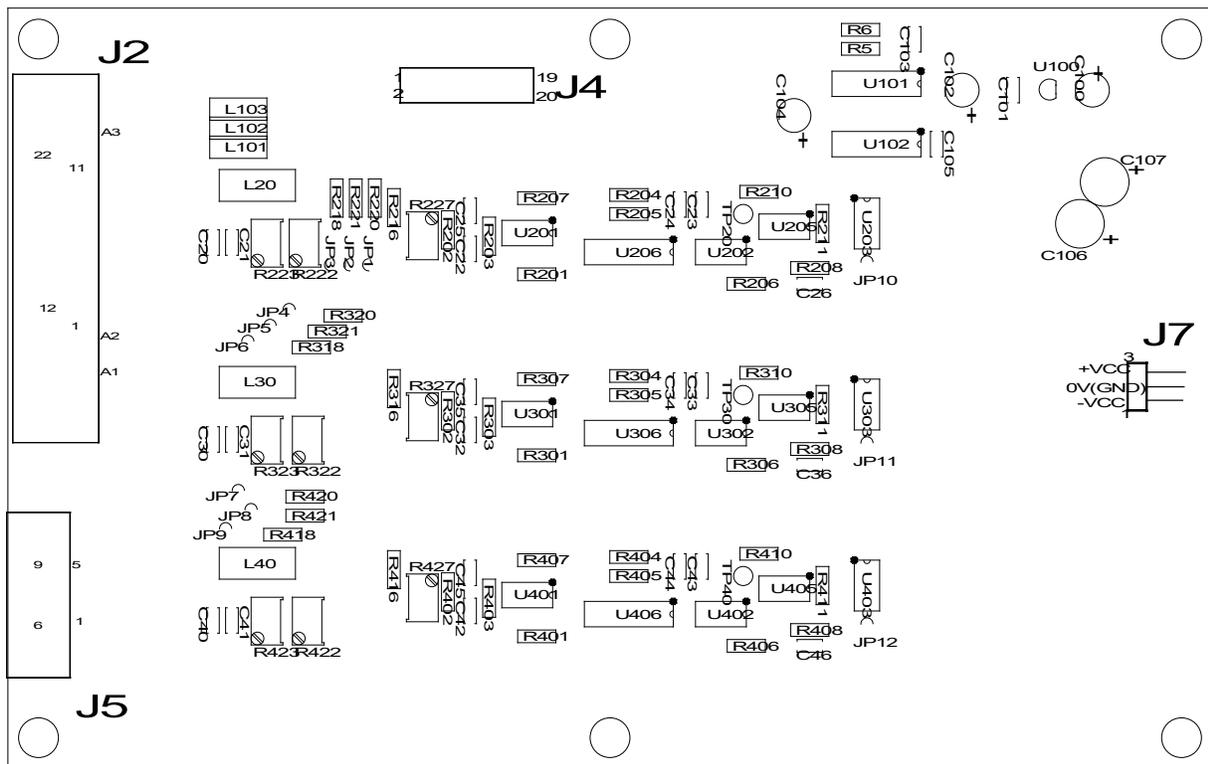


Figure 6-9 CCM-3 analog magnetometer PCB

1. Verify that the cable between the CCM-3 analog magnetometer and CCM-3 field controller PCB is properly connected.
2. Set the operating mode to Closed Loop.
3. Connect a Multimeter between the CCM-3 analog magnetometer PCB JP3 and ground.
4. Set the HCS01 Front Panel X-axis **Zero Adjust** control to 4000.
5. The magnitude of the measured voltage should be approximately 9 to 10 VDC.

6. If the measured voltage in step 5 is not within the specified limits then remove the cable between the CCM-3 analog magnetometer PCB and the CCM-3 field controller PCB; place a jumper between J7-1 and J7-3 of the CCM-3 field controller and measure the voltage on J7-3. It should be between 9 and 10 VDC.
7. If the voltage measured in step 6 is correct then replace the cable between the CCM-3 analog magnetometer PCB and the CCM-3 field controller PCB.
8. If the J7-3 voltage measured in step 6 is not within the specified range then the CCM-3 field controller PCB has failed. Replace the CCM-3 field controller PCB.
9. Reconnect the cable between the CCM-3 analog magnetometer PCB and the CCM-3 field controller PCB.

If the X axis was responding correctly but the Y or Z axis do not respond properly then use the above procedure to test the axis that is not responding. In the case of the Y axis substitute JP6 for JP3, J7-3 for J7-1 and J7-4 for J7-2. In the case of the Z axis substitute JP9 for JP3, J7-14 for J7-1 and J7-11 for J7-2.

#### **6.4.2.2 System in Open Loop Mode**

The *HCS01 Front Panel* program is communicating with the CCM-3 and the field at the center of the coil assembly is within the zero-adjustment range, but nothing happens when the *HCS01 Front Panel Zero Adjust* control is exercised in Open Loop mode but does work in Closed Loop mode.

In this case the BOPIF DUAL PCB or the cable connecting the CCM-3 field controller to the BOPIF DUAL PCB has failed.

1. Place the system into Open Loop mode.
2. Verify that the cable is properly connected to P1 of the CCM-3 field controller PCB.
3. Set the *HCS01 Front Panel Zero Adjust* control of the axis in question to 4000.
4. If the cable is properly connected measure the voltage between TP3 (DAC Zero) and TP5 (GND) on the BOPIF DUAL PCB in question. It should be between 9 and 10 VDC.
5. If the measured voltage is not within the range stated in step 4 check the pins of the BOPIF DUAL PCB cable connector to make sure they are properly seated.
6. If the connector pins are properly seated and the measured voltage is within the specified range but the zero adjustment still does not change the field in the test volume then replace the BOPIF DUAL PCB.

#### **6.4.3 Cannot Apply Field**

##### **6.4.3.1 System in Closed Loop Mode**

The *HCS01 Front Panel* program connects properly to the CCM-3 but changing the *SSMMF Front Panel Field Magnitude* control value in Closed Loop mode does not change the field in the 4-m coil test volume.

1. Connect LK3, LK4 and LK5 of the CCM-3 field controller PCB.
2. Set the **Field Magnitude** of the axis under question to 0 nT.
3. Connect a Multimeter between LK3 or LK4 or LK5 and GND depending on the axis in question. The voltage should be less than 1 millivolts.
4. Set the **Field Magnitude** of the axis under question to 200000 nT.
5. The voltage magnitude should change to between 9 and 9.54 VDC.
6. If the voltage does not change or the change is not within the specified limits, replace the 20-bit DAC daughter board of the axis in question otherwise proceed to step 7.
7. Turn off the CCM-3.
8. Remove the link associated with the axis in question.
9. Measure the resistance between the two terminals of the link for the axis in question.
10. If the resistance is high (K $\Omega$  or higher) the calibration winding in the CCM-3 sensor is open. Check the sensor cable and correct the condition otherwise continue to step 11.
11. If the resistance is low (a few ohms) the calibration winding in the CCM-3 is probably shorted. Correct the condition and check to see if the problem has been resolved.
12. Remove LK3, LK4 and LK5 of the CCM-3 field controller PCB.

#### **6.4.3.2 System in Open Loop Mode**

The *HCS01 Front Panel* program connects properly to the CCM-3 but changing the *HCS01 Front Panel Field Magnitude* control value in Open Loop mode does not change the field in the 4-m coil test volume but does change it in Closed Loop mode.

In this case the BOBIF DUAL PCB or the cable connecting the CCM-3 field controller to the BOPIF DUAL PCB has failed.

1. Connect LK3, LK4 and LK5 of the CCM-3 field controller.
2. Place the system into Open Loop mode.
3. Verify that the cable is properly connected to P1 of the CCM-3 field controller PCB.
4. Set the **Field Magnitude** of the axis under question to 0 nT.
5. Connect a Multimeter between LK3 or LK4 or LK5 and GND depending on the axis in question. The voltage should be less than 1 millivolts.
6. Set the **Field Magnitude** of the axis under question to 200000 nT. The voltage magnitude should change to between 9 and 9.54 VDC.

7. If the cable is properly connected measure the voltage between TP1 (DAC Field) and TP5 (GND) on the BOPIF DUAL PCB in question. It should be between 9 and 9.54 VDC.
8. If the measured voltage is not within the range stated in step 7 check the pins of the BOPIF DUAL PCB cable connector to make sure they are properly seated.
9. If the connector pins are properly seated and the measured voltage is within the specified range but the field adjustment still does not change the field in the test volume then replace the BOPIF DUAL PCB.
10. Remove LK3, LK4 and LK5 of the CCM-3 field controller.

#### 6.4.4 Miscellaneous Problems

There may be other problems that have symptoms and solutions other than the ones described above. In general check the cable connections, CCM-3 analog magnetometer and the CCM-3 field controller boards whenever an unexplained problem occurs. If the cause of the problem cannot be determined then call MEDA, Inc. at 703-996-8990 or send an email to [sales@meda.com](mailto:sales@meda.com) for assistance.

## 7 SAFETY CONSIDERATION

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This section provides general safety guidelines when operating the HCS01.

### 7.1 EQUIPMENT SAFETY

The SSMMF HCS01 coil system includes a mixture of commercial off-the-shelf (COTS) components and components that were designed by MEDA specifically for HCS01 systems. Below is a list of the major components of the system:

#### COTS:

1. Kepco Model BOP 72-6D 400 Watt Bipolar Operation Power Supply.
2. Keithley Model 2701 Ethernet Multimeter/Data Acquisition System (optional).
3. BK Precision Model 9210 200-Watt Multi-Range DC Power Supply (optional).
4. Eaton Model T982C1-F-SL-015 Power Distribution Unit.
5. DIGI Model CC iMX6UL Pro Single Board Computer (included in the CCM-3).

**Please refer to the individual COTS User's or Operation and Maintenance Manuals for specific safety precautions associated with the equipment. Under no circumstance should a User of the HCS01 system remove covers from the equipment or attempt to repair the equipment unless authorized by the manufacturer. MEDA is not responsible for any injuries to personnel or equipment if there is an unauthorized attempt to repair any of the equipment associated with the HCS01.**

#### CUSTOM:

1. CCM-3 Control Magnetometer

- a. CCM-3 Analog Magnetometer PCB
  - b. CCM-3 Field Controller PCB
2. BOPIF DUAL PCB.

The custom designed CCM-3 Control Magnetometer consumes very little power (less than 15 Watts). It uses 115 VAC 60 Hz power and this power is supplied to an AC/DC power supply inside the CCM-3 chassis (see Fig. 6-1). The AC input terminals are recessed to protect personnel from accidentally touching them but it is possible for someone working inside the unit to receive a shock. Only MEDA authorized personnel are permitted to perform work inside the CCM-3.

## **7.2 OCCUPATIONAL AND GENERAL EXPOSURE TO STATIC MAGNETIC FIELDS**

The static magnetic fields generated by the HCS01 are very small (less than 0.2 mT). In accordance with the **ICNIRP GUIDELINES ON LIMITS OF EXPOSURE TO STATIC MAGNETIC FIELDS**, this field magnitude is considered safe for occupational or general exposure.

## **7.3 EFFECTS ON IMPLANTED MEDICAL DEVICES**

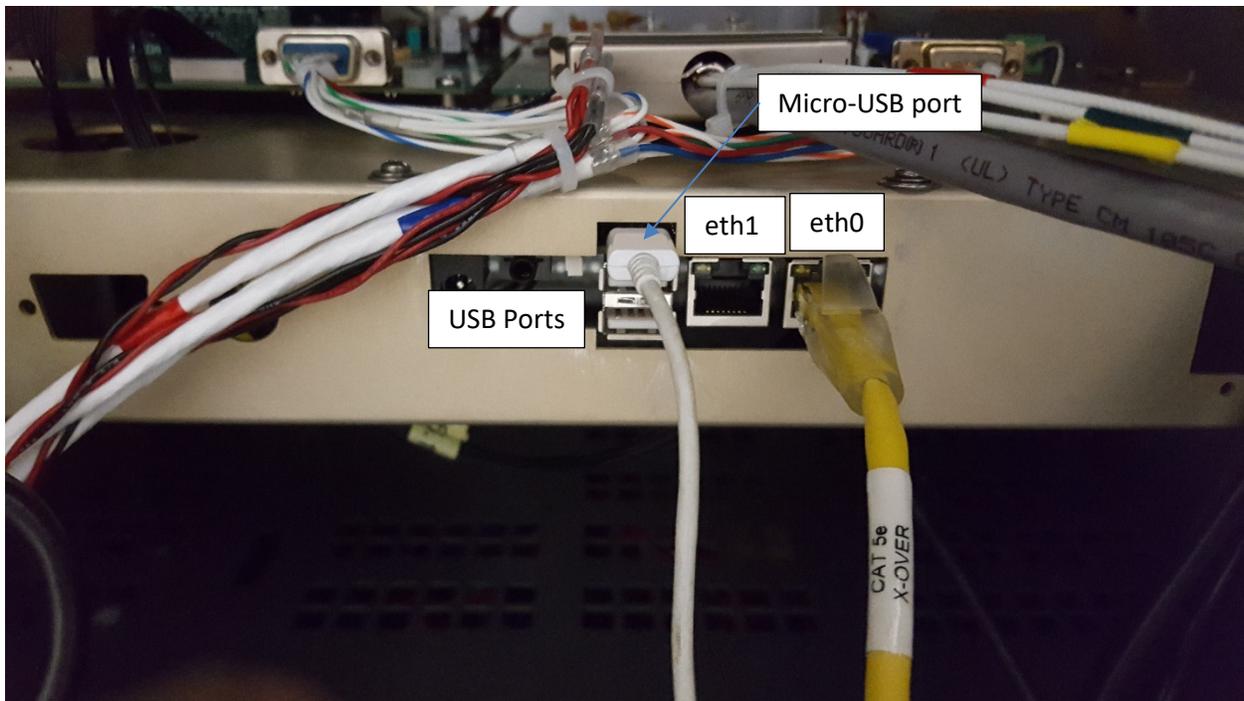
The 0.2 mT peak field that the HCS01 can generate is considered safe for personnel who have implanted medical devices according to the **ICNIRP GUIDELINES ON LIMITS OF EXPOSURE TO STATIC MAGNETIC FIELDS**.

## INTRODUCTION

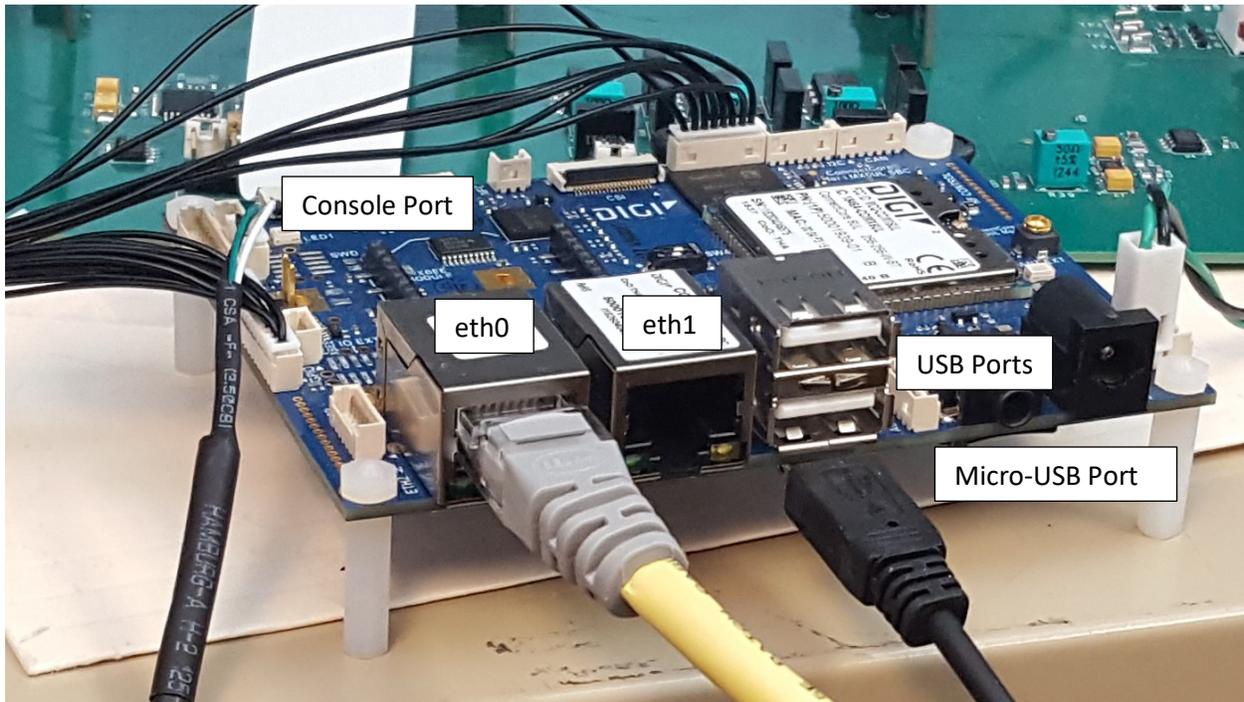
The CCM-3 Field Controller in the HCS01 coil system contains a Single Board Computer (SBC) that is used to control the functions of the HCS01. Under normal circumstances the only connection required to communicate with the CCM-3 is through a micro-USB port on the back of the SBC. The SBC is mounted to the bottom of the chassis with access to its connectors available through the chassis back panel. See the following figure.

***Only qualified personnel who are experienced in Linux operating systems (OS) and with the CCM-3 Field Controller should connect to the SBC in the CCM-3 as described below otherwise it is possible to damage the SBC and render the CCM-3 inoperable.***

The main reasons for connecting to the SBC would be to troubleshoot problems or to update the software to correct bugs or add enhancements. Utility programs can be transferred to and executed on the SBC through the eth0 or eth1 ethernet connections. Files can also be installed on the SBC using a USB memory stick.



The next figure shows a top view of the SBC where the console connector is located.



The SBC has two (2) Ethernet ports (eth0 and eth1), two USB ports, one Console port and one micro-USB port.

The SBC operating system (OS) is a Busybox Linux version with Digi Embedded Yocto 2.4-r2-beta. The Console serial port is /dev/ttyMXC4 and it simulates an RS232-to-USB port. This is the port used for normal console communications with the OS.

The following sections described how to communicate with the SBC through the Console port, eth0 or eth1 and how to use the USB ports to transfer files. The highlighted text is a typical prompt that the user would see when using a terminal window.

## CONSOLE PORT

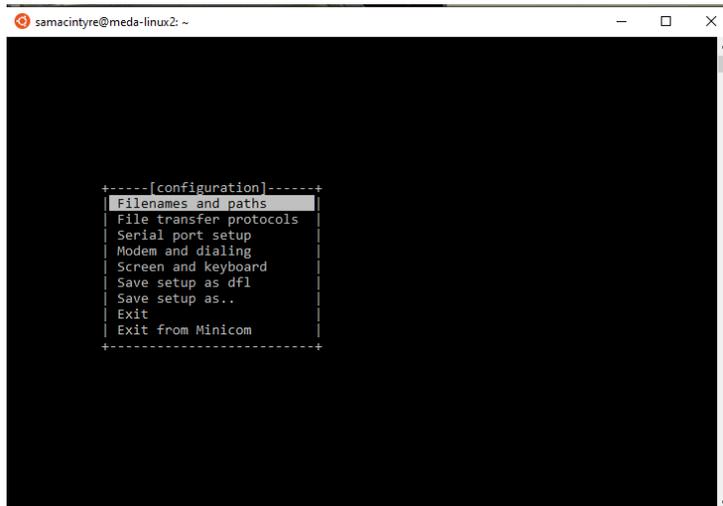
The console port is the primary way to communicate with the SBC Linux OS. The simplest connection is between the SBC and another PC with a Linux OS but serial port applications on Microsoft Windows can also be used.

### Linux OS Connection

The procedure below assumes the User is communicating with the SBC using the *minicom* Linux application. The User must have administrative (root) privileges. Use the following steps to connect:

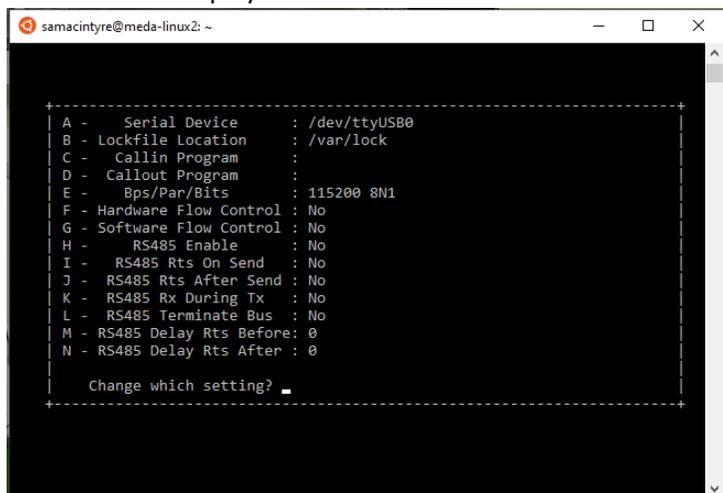
1. Turn the CCM-3 power off.
2. Connect the cable between the Console port and any USB port of the PC.
3. Apply power to the CCM-3 and wait approximately 30 seconds for the CCM-3 to boot.

4. A serial port will be added as `/dev/ttyUSBx` where `x` is the number of the new serial port.
5. In the Linux PC open a terminal window.
6. On the PC at the prompt type the following:  
`samacintyre@meda-linux2:~$ sudo minicom -s`  
This will bring up the following dialog screen:



```
samacintyre@meda-linux2: ~  
-----[configuration]-----  
File transfer protocols  
Serial port setup  
Modem and dialing  
Screen and keyboard  
Save setup as dfl  
Save setup as..  
Exit  
Exit from Minicom
```

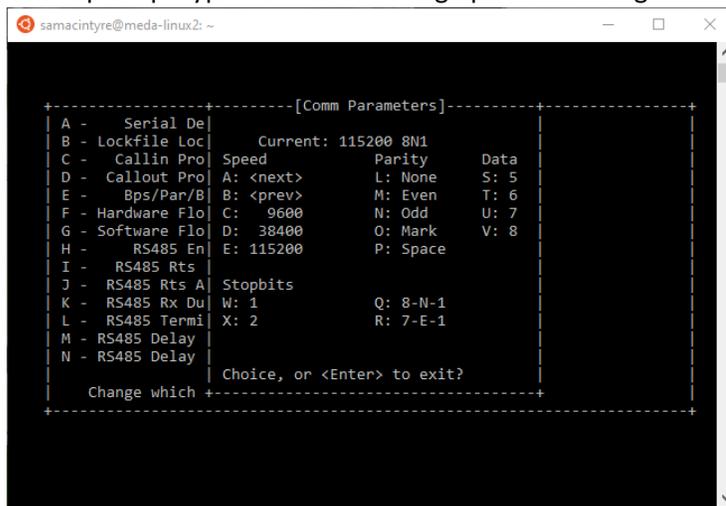
7. Use the down arrow to highlight *Serial port setup* selection and press enter. The following screen will be displayed:



```
samacintyre@meda-linux2: ~  
-----  
A - Serial Device      : /dev/ttyUSB0  
B - Lockfile Location  : /var/lock  
C - Callin Program     :  
D - Callout Program    :  
E - Bps/Par/Bits       : 115200 8N1  
F - Hardware Flow Control : No  
G - Software Flow Control : No  
H - RS485 Enable       : No  
I - RS485 Rts On Send  : No  
J - RS485 Rts After Send : No  
K - RS485 Rx During Tx  : No  
L - RS485 Terminate Bus : No  
M - RS485 Delay Rts Before: 0  
N - RS485 Delay Rts After : 0  
  
Change which setting?   
-----
```

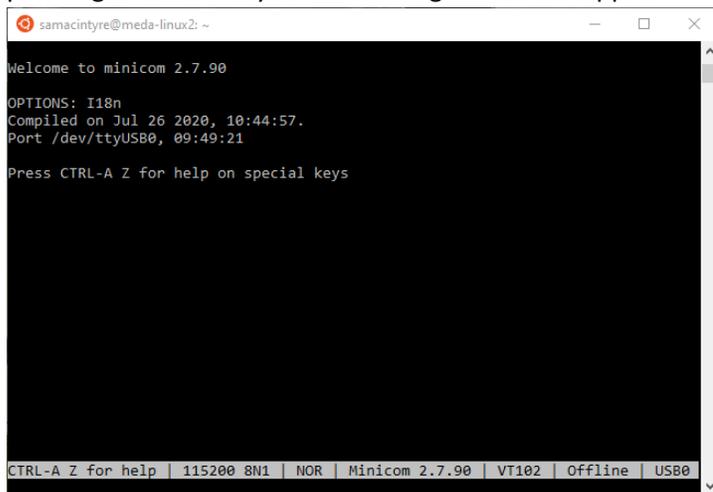
8. Type `A` at the prompt which will place the cursor at the end of the *Serial Device* selection. Edit the line to be `/dev/ttyUSBx` where `x` is the number for the serial port connected to the SBC and press the *Enter* key.

9. At the prompt type E which will bring up the following screen:



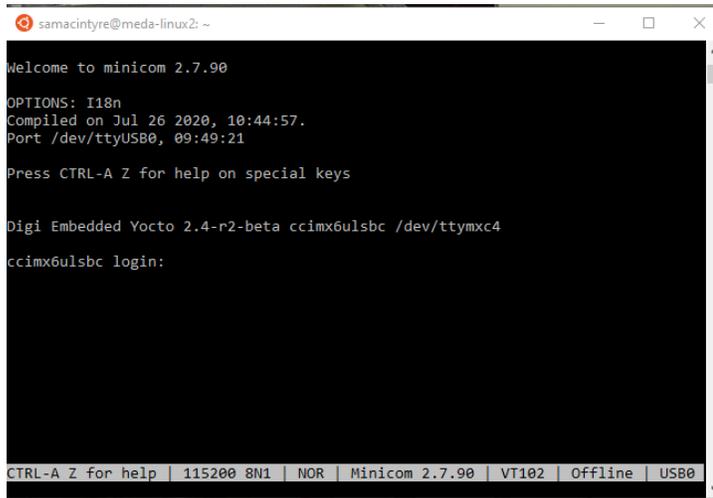
```
samacintyre@meda-linux2: ~  
-----[Comm Parameters]-----  
A - Serial De|  
B - Lockfile Loc      Current: 115200 8N1  
C - Callin Pro| Speed      Parity      Data  
D - Callout Pro| A: <next>    L: None    S: 5  
E - Bps/Par/B| B: <prev>    M: Even    T: 6  
F - Hardware Flo| C: 9600     N: Odd     U: 7  
G - Software Flo| D: 38400    O: Mark    V: 8  
H - RS485 En| E: 115200   P: Space  
I - RS485 Rts|  
J - RS485 Rts A| Stopbits  
K - RS485 Rx Du| W: 1        Q: 8-N-1  
L - RS485 Termi| X: 2        R: 7-E-1  
M - RS485 Delay|  
N - RS485 Delay|  
Choice, or <Enter> to exit?  
Change which +-----+
```

10. Set the *Speed* to 115200 (E), *Parity* to None (L), *Data* to 8 (V) and *Stopbits* to 1 (W). Then press the *Enter* key to exit. The *Bps/Par/Bits* entry should be 115200 8N1.
11. Press the *Enter* key to return to the main menu.
12. Use the down arrow to highlight the *Save setup as dfl*. This will save the configuration data as the default when using *minicom*.
13. Use the down arrow to highlight *Exit from Minicom* to return to the Linux prompt.
14. At the Linux prompt type the following:  
`samacintyre@meda-linux2:~$ sudo minicom`
15. You will be prompted to enter your password. Enter your password for the Linux PC followed by pressing the *Enter* key. The following screen will appear:



```
samacintyre@meda-linux2: ~  
Welcome to minicom 2.7.90  
OPTIONS: I18n  
Compiled on Jul 26 2020, 10:44:57.  
Port /dev/ttyUSB0, 09:49:21  
Press CTRL-A Z for help on special keys  
CTRL-A Z for help | 115200 8N1 | NOR | Minicom 2.7.90 | VT102 | Offline | USB0
```

16. This screen indicates that the minicom serial port is active. Press the *Enter* key to go forward. The following screen will appear:



```

Welcome to minicom 2.7.90

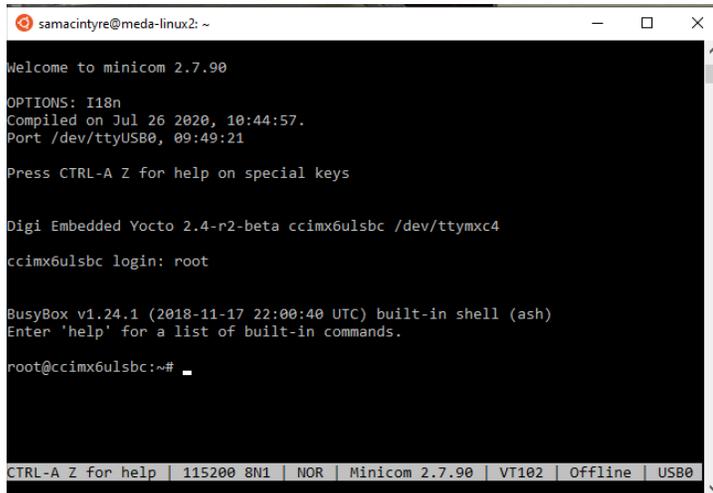
OPTIONS: I18n
Compiled on Jul 26 2020, 10:44:57.
Port /dev/ttyUSB0, 09:49:21

Press CTRL-A Z for help on special keys

Digi Embedded Yocto 2.4-r2-beta ccimx6ulsbc /dev/ttyMXC4
ccimx6ulsbc login:

```

17. Type *root* at the login prompt. The following screen will appear:



```

Welcome to minicom 2.7.90

OPTIONS: I18n
Compiled on Jul 26 2020, 10:44:57.
Port /dev/ttyUSB0, 09:49:21

Press CTRL-A Z for help on special keys

Digi Embedded Yocto 2.4-r2-beta ccimx6ulsbc /dev/ttyMXC4
ccimx6ulsbc login: root

BusyBox v1.24.1 (2018-11-17 22:00:40 UTC) built-in shell (ash)
Enter 'help' for a list of built-in commands.

root@ccimx6ulsbc:~#

```

The PC is now connected to the SBC. The user can use normal Linux commands to navigate and manipulate the SBC OS.

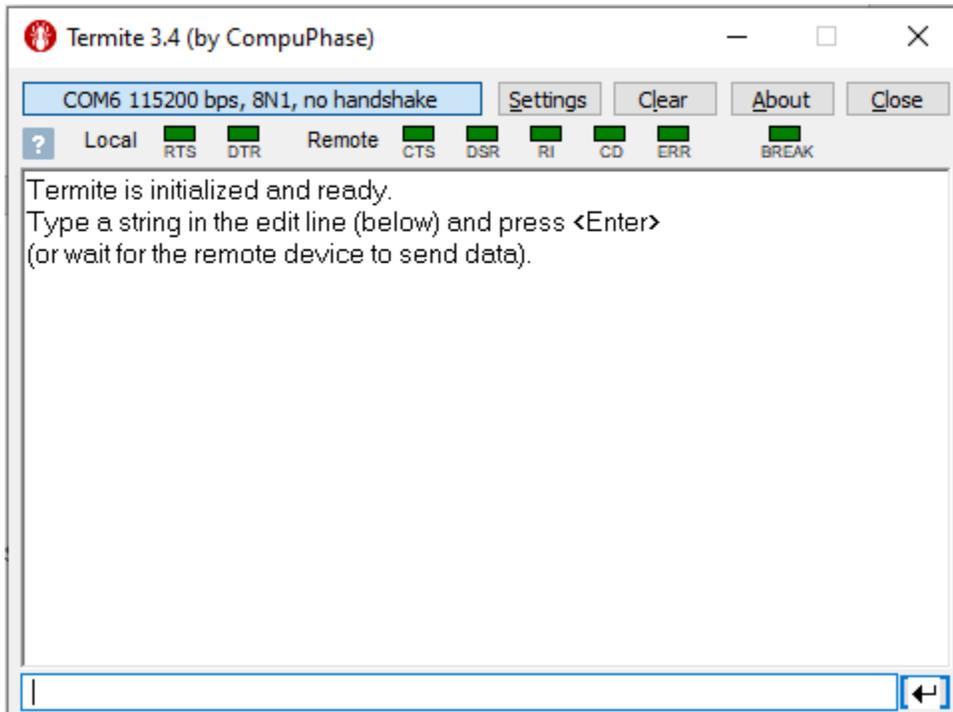
To return to the Linux PC close the terminal window.

### Window Connection

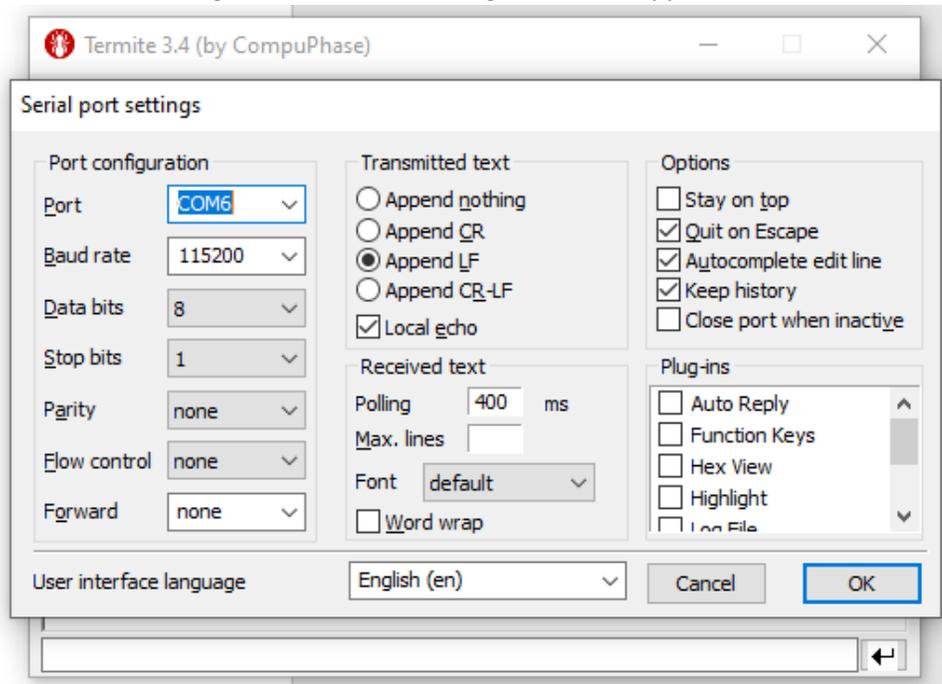
There are various applications that can be used on a Microsoft Windows OS to connect to the SBC Console port. One of the simplest and easiest to use is Termite. It is a free program and can be downloaded from [https://www.compuphase.com/software\\_termite.htm](https://www.compuphase.com/software_termite.htm). The following procedure assumes that Termite will be used to connect to the Console terminal of the SBC.

1. Connect the CCM-3 SBC Console port to any USB port in a PC with a Windows OS.

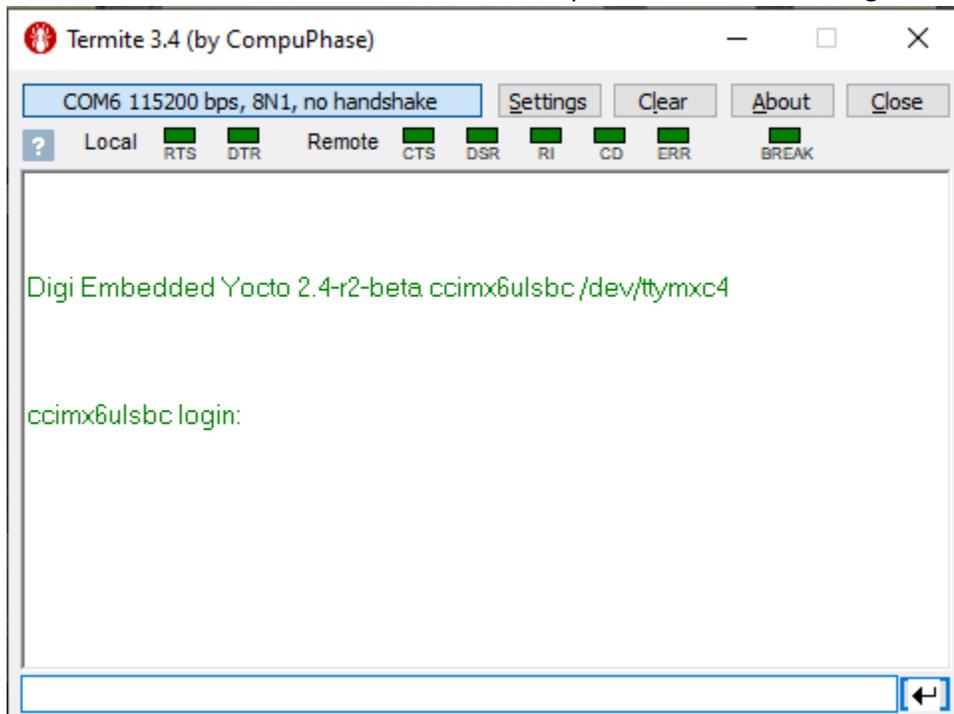
2. Apply power to the CCM-3 and wait approximately 30 seconds for the CCM-3 to boot.
3. Start Termite. The following screen will appear.



4. Click on the Settings button. The following screen will appear.

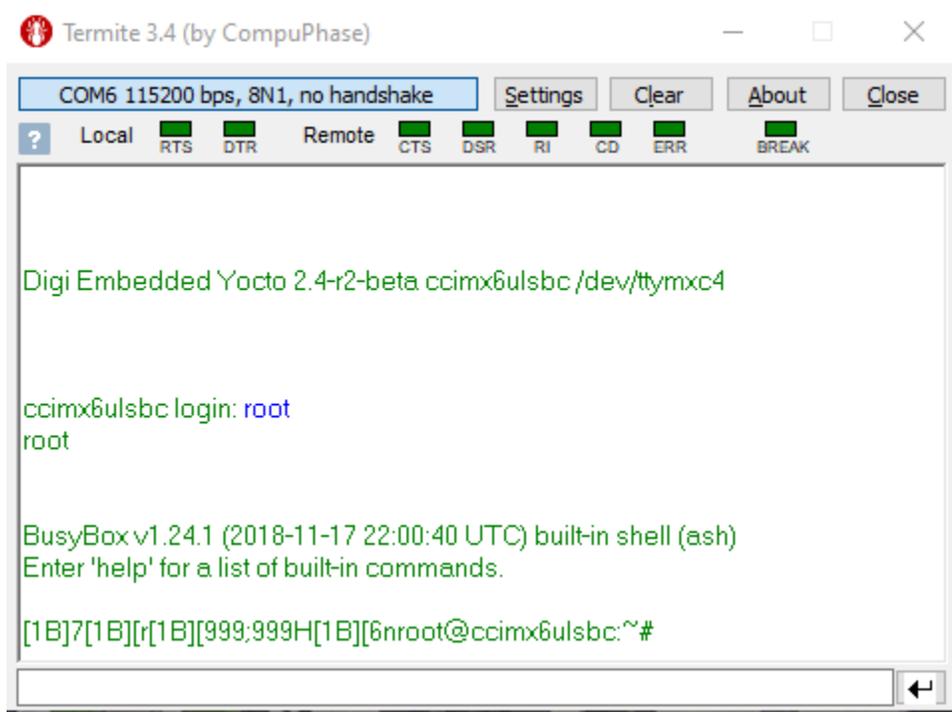


5. Select the COM port that was added to the Serial Ports of the OS. The COM port number can be found by starting *Device Manager* and expanding *Ports (COM & LPT)*. The name of the port will be *Prolific USB-to-Serial Port*. The COM port number will be in parentheses following the name.
6. Set the serial port settings to:  
Baud rate: 115200  
Data bits: 8  
Stop bits: 1  
Parity: none  
Flow control: none
7. Local echo: uncheck  
Keep all of the other default values and press *OK* to continue.
8. Place the cursor in the bottom text control and press *Enter*. The following screen will appear.



Note all commands to the SBC are typed in the bottom edit box.

9. Type root to log in. The following screen will appear.



There may be some extra characters at the beginning of the prompt but future prompts will be clean.

The PC is now connected to the SBC and Linux commands can be entered to control the SBC.

## CONNECT THROUGH ETH0

The eth0 ethernet connection on the SBC has a static IP address of 192.168.1.101. To communicate with the SBC a PC can be configured with a static IP address which is on the same network (e.g. 192.168.1.102). Each operating system uses a different method for accomplishing this so refer to the OS documentation to determine how to set up an ethernet interface with a static IP address. Use a net mask of 255.255.255.0. No gateway address is needed but if one is required use 192.168.1.100.

Once the PC has been configured with a static up address use a crossover ethernet cable (usually colored yellow) to connect the SBC to the PC.

To communicate with the SBC depends on the OS being used but the connection in both cases is thorough a secure shell (SSH) port. The method used for a Windows 10 and a Linux Ubuntu OS are described below.

### Windows 10

1. Right click on the Start menu icon and select Window **PowerShell (Admin)**.
2. At the prompt type the following command:

```
PS C:\WINDOWS\system32> ssh root@192.168.1.101
```

3. The first time you connect you will be shown a message stating that the connection cannot be authenticated and asked if you wish to proceed. Answer *yes*.
4. You will be connected to the SBC and the prompt shown in the figure above will be displayed. No password will be required since the *ssh* connection is as the root user.

The PC is now connected to the SBC Linux OS and Linux commands can be used to control and manipulate the SBC.

### Ubuntu

1. Open a new window.
2. At the prompt type the following command:  

```
samacintyre@meda-linux2:~$ ssh root@192.168.1.101
```
3. The first time you connect you will be shown a message stating that the connection cannot be authenticated and asked if you wish to proceed. Answer *yes*.
4. You will be connected to the SBC and the prompt shown in the figure above will be displayed. No password will be required since the *ssh* connection is as the root user.

The PC is now connected to the SBC Linux OS and Linux commands can be used to control and manipulate the SBC.

### CONNECT THROUGH ETH1

The SBC *eth1* ethernet interface gets its IP address from a Dynamic Host Configuration Protocol (DHCP) server so the SBC can be connected to a private network through a router that assigns IP addresses. The same procedures described above for the Window 10 and Ubuntu connections can be used. Just substitute the IP address assigned by the router for the static IP address.

To determine the SBC IP address, you will need to first connect to the SBC through the Console port and use the *ifconfig eth1* command to list the IP address of the *eth1* interface.

### TRANSFER FILES THROUGH THE USB PORT

The USB ports can be used to transfer files between the SBC and USB disk drive. This may be the simplest method to accomplish this task. The SBC includes a driver for communicating with the USB disk drive.

1. Connect to the Console port using any of the methods described above.
2. Plug in a USB disk drive into either USB ports.
3. Change the SBC directory to */run/media/sda1*.

You are now connected to the USB disk. To see what is on the disk run the *ls -l* command from the prompt. You can use the Linux *cp* command to copy files between the SBC and the USB disk drive.

If you connect a second USB drive it will be located at */run/media/sdb1*.